STEREO
End of Prime Mission Review

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Presentations

- Mission overview [15 m]
- Systems and engineering aspects of ops [45 m]
  - How these affected science [10 m]
- Foreign partnerships/issues [15 m]
- Science overview [20 m]
  - How did we get to full completion of (nearly all) Level-1 requirements [10 m]
  - 2 counterexamples [10 m]
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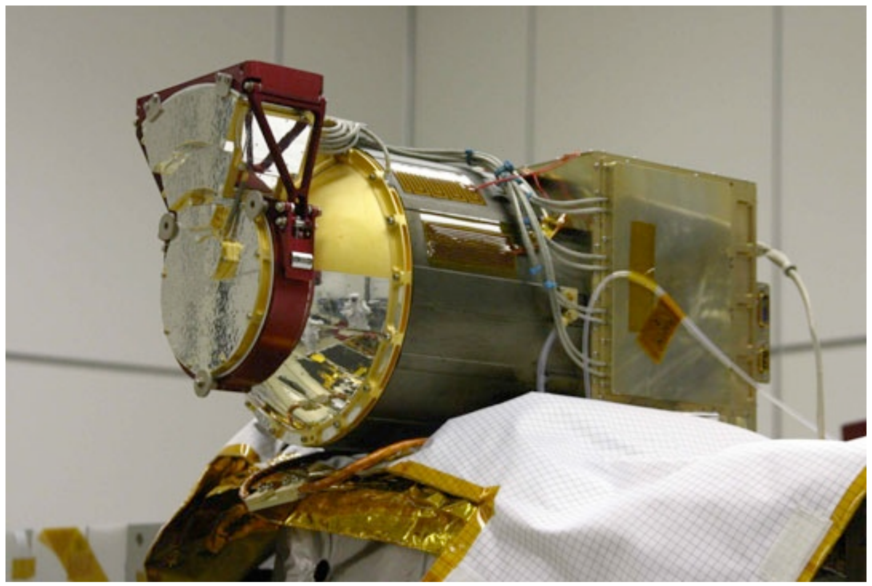
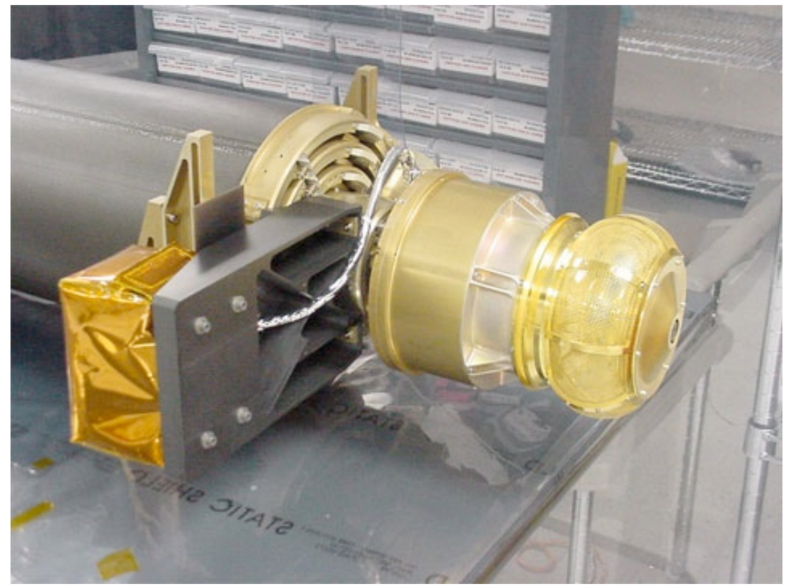
Mission overview (I)

- First NASA-managed STP mission
- Two nearly identical spacecraft in heliocentric orbits
  - differing orbit sizes to yield 22°/year separation rate from Sun-earth line
- Four PI instrument suites
  - SWAVES - broad frequency response RF detection of Type II, III bursts
  - PLASTIC - solar wind plasma and suprathermal ion composition measurements
  - IMPACT - energetic electrons and ions, magnetic field
  - SECCHI - EUV, coronagraphs and heliospheric imagers

STEREO instrumentation



PLASTIC



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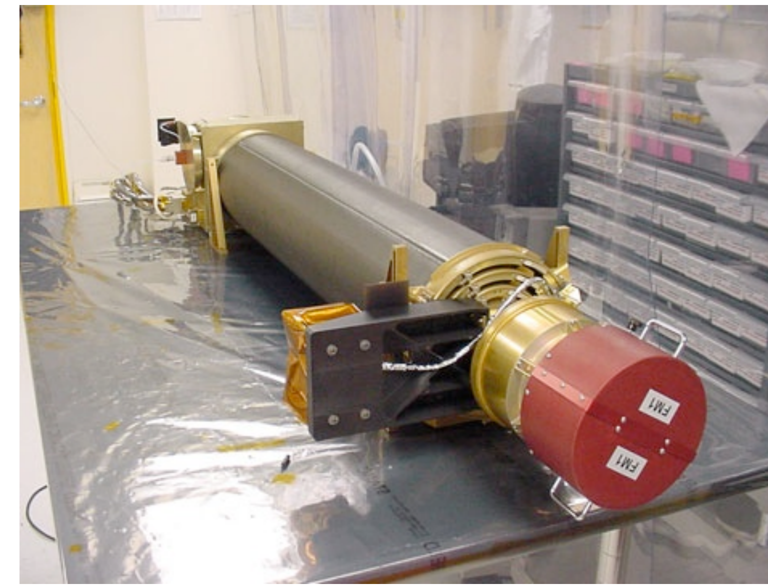

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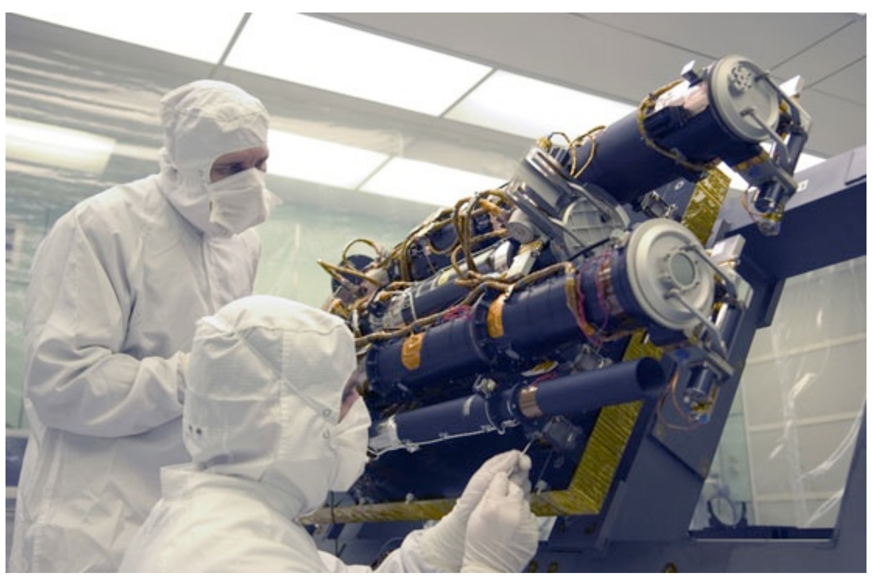
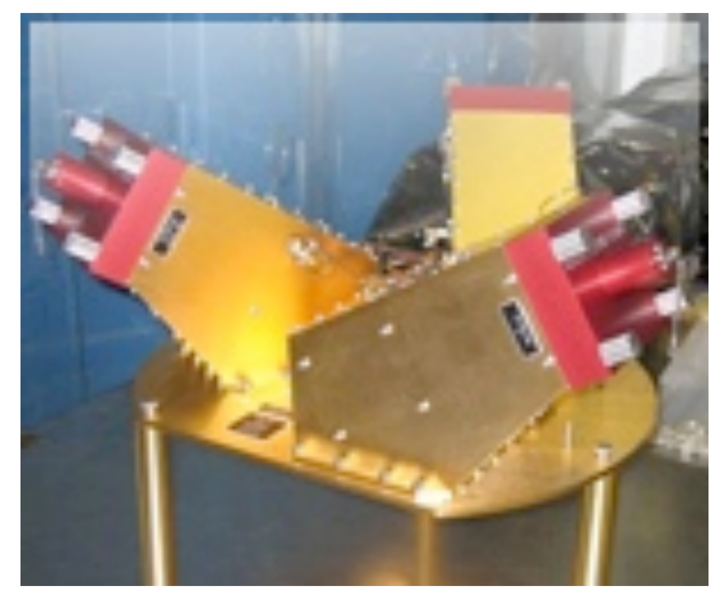


SECCHI SCIP

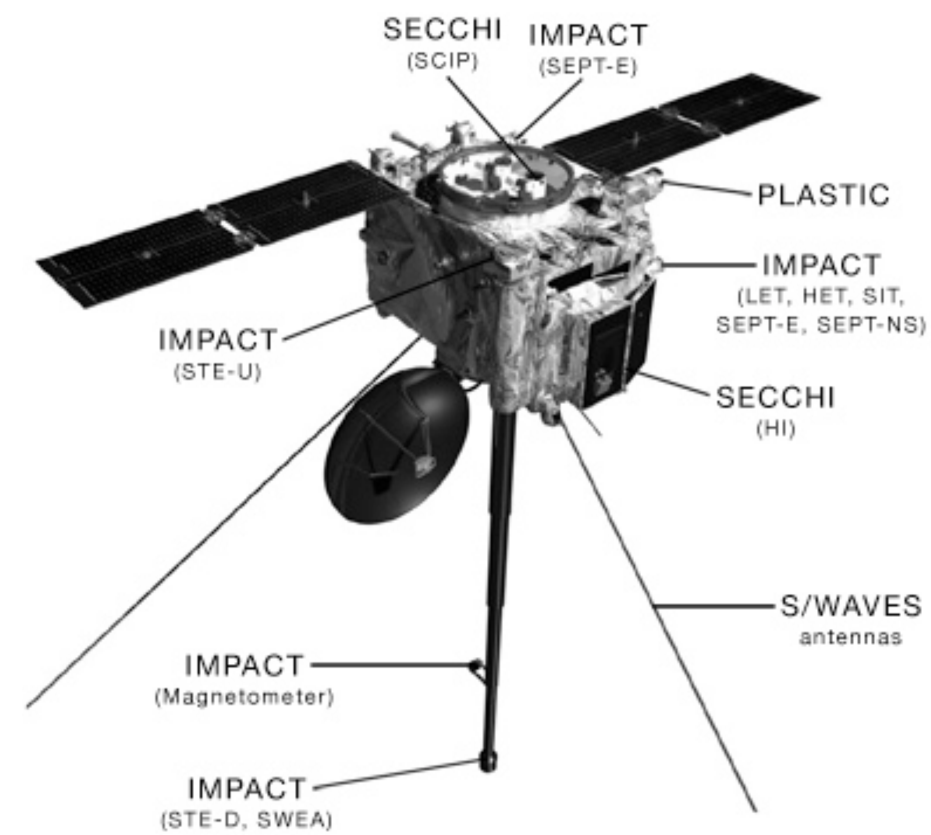
SECCHI HI



SWAVES

Mission overview (II)

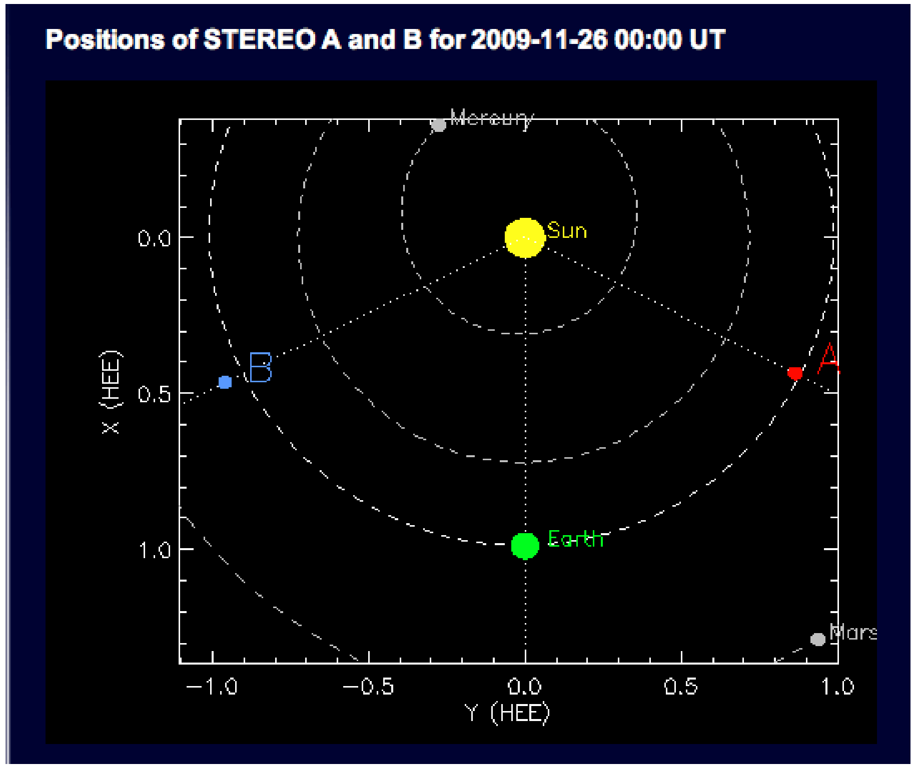
- Spacecraft
  - Built and operated by JHU APL
  - 620 kg each with propellant
  - 1 Gbyte SSR/spacecraft
  - Up to 720 kbps downlink
  - Attitude
    - control to 7 arc sec
    - knowledge to 0.1 arc sec



- Steerable HGAs plus s/c roll make it possible to continue to observe after s/c pass 180° from Sun-earth line

Mission overview (III)

- Milestones:
    - Launch: 2006 October 25 (26 UTC)
    - A heliocentric orbit: 2006 December 16
    - B heliocentric orbit: 2007 January 22
    - Stereoscopic imaging: 2007 May
    - Quadrature: 2009 January 24
    - B reaches L5: 2009 October 26
    - 180° separation: 2011 February 6 (Superbowl XLV)



STEREO science objectives

STEREO MISSION REQUIREMENTS DOCUMENT 460-RQMT-0001 REV D

3.0 Mission Objectives

3.1 Science Objectives

The STEREO mission, a part of NASA's Sun-Earth Connection program, is aimed at studying and characterizing solar Coronal Mass Ejection (CME) disturbances from their origin through their propagation in interplanetary space and their effects on Earth.

The major scientific objectives for the STEREO mission are to:

- Understand the causes and mechanisms of CME initiation;
- Characterize the propagation of CMEs through the heliosphere;
- Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium; and
- Develop a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind.

The secondary mission objective is:

- To provide a continuous low rate data stream for the purposes of space weather specification and possible prediction of geomagnetic storms.

Level 1 Requirements (I)

SCIENTIFIC OBJECTIVE		MEASUREMENT REQUIREMENT	
1	Understand the causes and mechanisms of CME initiation	A.	Determine the CME initiation time to an accuracy of order 10 [120] minutes
		B.	Determine the location of CME initiation to within +/- 5 [30] degrees of solar latitude and longitude
2	Characterize the propagation of CMEs through the heliosphere	C1.	Determine the evolution of the CME mass distribution and the longitudinal extent to an accuracy of +/- 5 [30] degrees as it propagates in the low corona
		C2.	Determine the evolution of the CME mass distribution and the longitudinal extent to an accuracy of +/- 5 [30] degrees as it propagates in the upper corona
		C3.	Determine the evolution of the CME mass distribution and the longitudinal extent to an accuracy of +/- 5 [30] degrees as it propagates in the IPM.
		D1.	Determine the CME and MHD shock speeds accurate to +/- 10 [30]% as it propagates from the low corona
		D2.	Determine the CME and MHD shock speeds accurate to +/- 10 [30]% as it propagates from the upper corona
		D3.	Determine the CME and MHD shock speeds accurate to +/- 10 [30]% as it propagates in the IPM
		E1.	Determine the direction of CME and MHD shock propagation to within +/- 5 [30] degrees of latitude and longitude as the CME evolves from the low corona to 1 AU
		E2.	Determine the direction of CME and MHD shock propagation to within +/- 5 [30] degrees of latitude and longitude as the CME evolves in the upper corona
		E3.	Determine the direction of CME and MHD shock propagation to within +/- 5 [30] degrees of latitude and longitude as the CME evolves in the IPM

Level I Requirements (II)

SCIENTIFIC OBJECTIVE		MEASUREMENT REQUIREMENT	
3	Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium	F.	Develop distribution functions to an accuracy of ± 10% for electrons and/or ions with energies typical of solar energetic particle populations
		G.	Location of particle acceleration in the low corona to within 300,000 km [500,000 km] in radius and in interplanetary space to within 20 degrees [40 degrees] in total longitude
4	Develop a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind	H.	Obtain a time series of the solar wind temperature accurate to ±10 [30]% at two points separated in solar longitude
		I.	Obtain a time series of the solar wind density accurate to ± 10[30] at two points separated in solar longitude
		J.	Obtain a time series of the solar wind speed accurate to ± 10 [30]% at two points separated in solar longitude
		K.	Measure global magnetic field topology near the ecliptic by determining the magnetic field direction to ± 10 degrees.

Level 1 Requirements (II)

SCIENTIFIC OBJECTIVE		MEASUREMENT REQUIREMENT	
3	Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium	F.	Develop distribution functions to an accuracy of ± 10% for electrons and/or ions with energies typical of solar energetic particle populations
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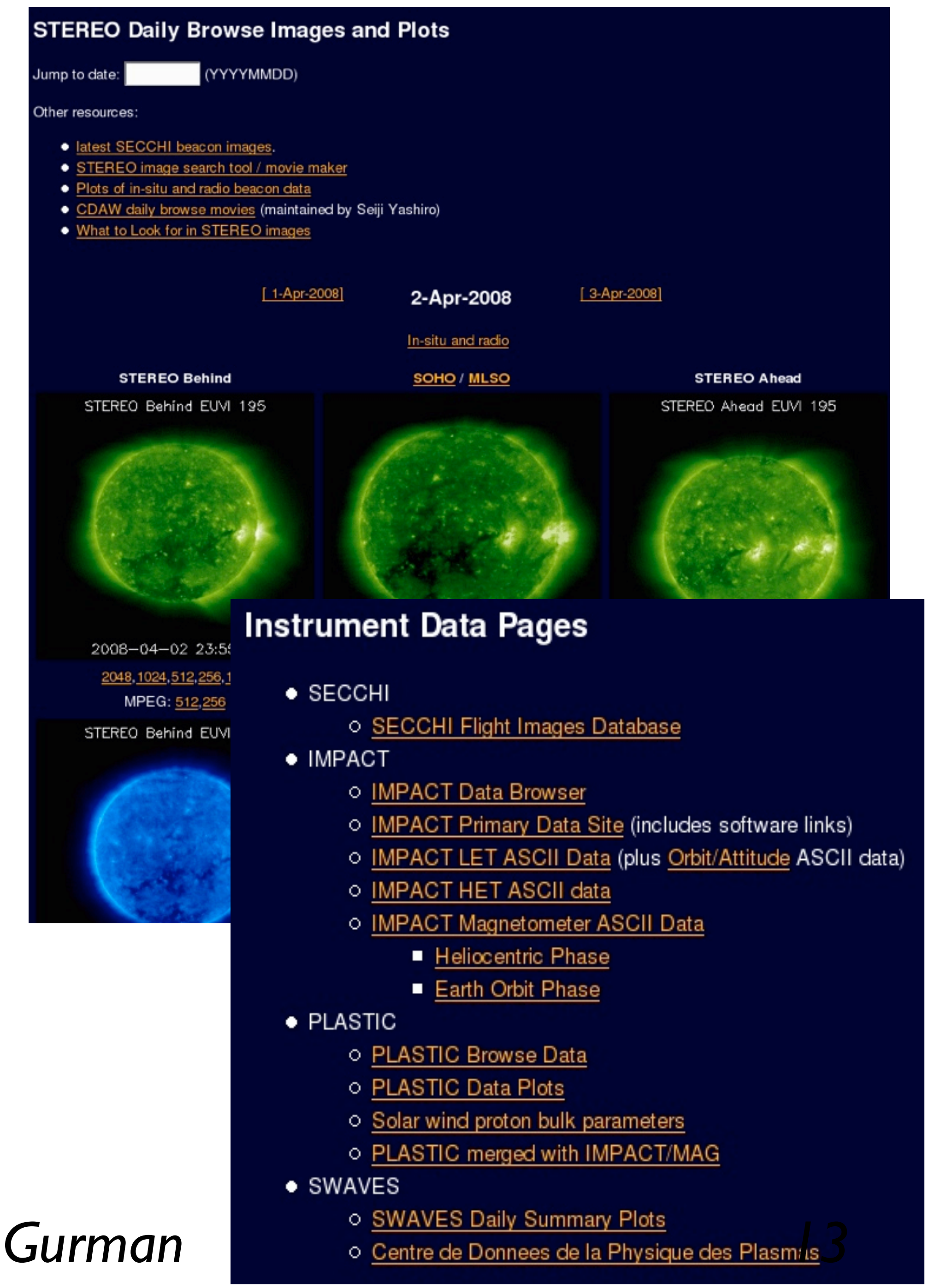
4	Develop a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind	H.	Obtain a time series of the solar wind temperature accurate to ±10 [30]% at two points separated in solar longitude
		I.	Obtain a time series of the solar wind density accurate to ± 10[30] at two points separated in solar longitude
		J.	Obtain a time series of the solar wind speed accurate to ± 10 [30]% at two points separated in solar longitude
		K.	Measure global magnetic field topology near the ecliptic by determining the magnetic field direction to ± 10 degrees.

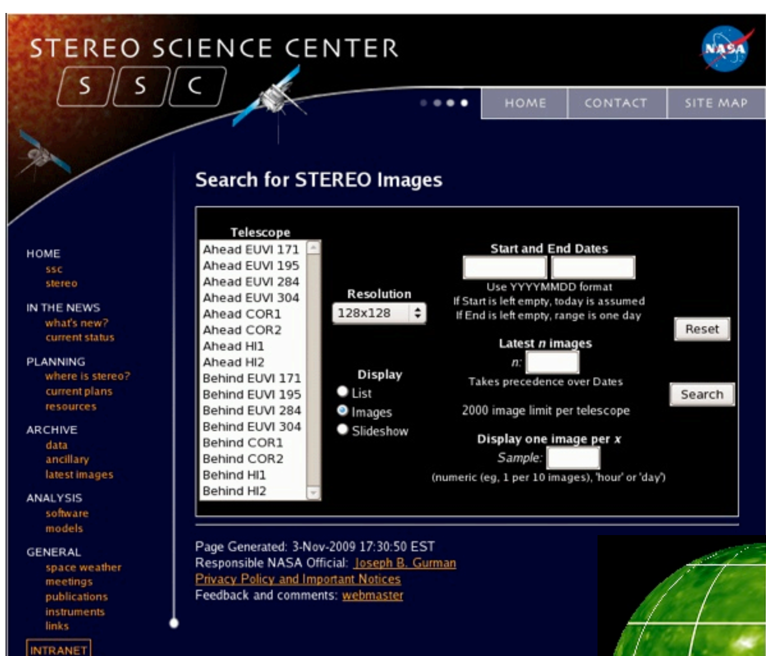
Data Availability

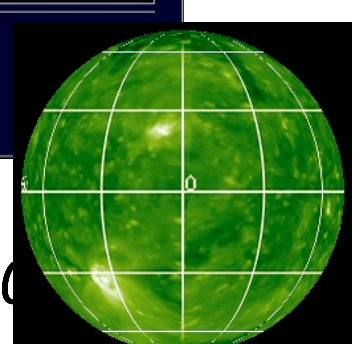
- STEREO Science Center (SSC) currently holding **~24 TB** of data
- **Data available** from
  - SSC website
  - Virtual Solar Observatory (VSO)
  - Virtual Space Physics Observatory (VSPO)
  - CDAWeb Plus (IMPACT, SWAVES)
  - Instrument-specific websites (e.g. UCLA IGPP Space Physics Center, UNH, &c.)
- **Instrument resource pages** for software and documentation, based on *SOHO* experience
- **Event lists** maintained by instrument teams
- **Daily browse** images and plots.

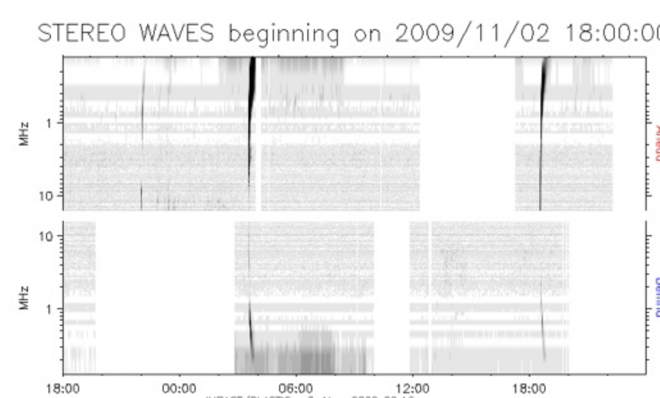


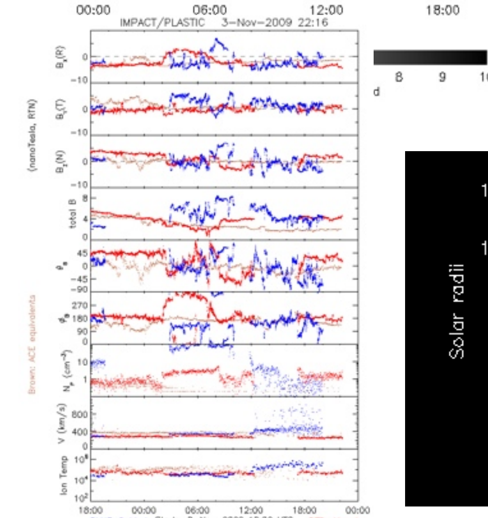
Space Weather Beacon processing

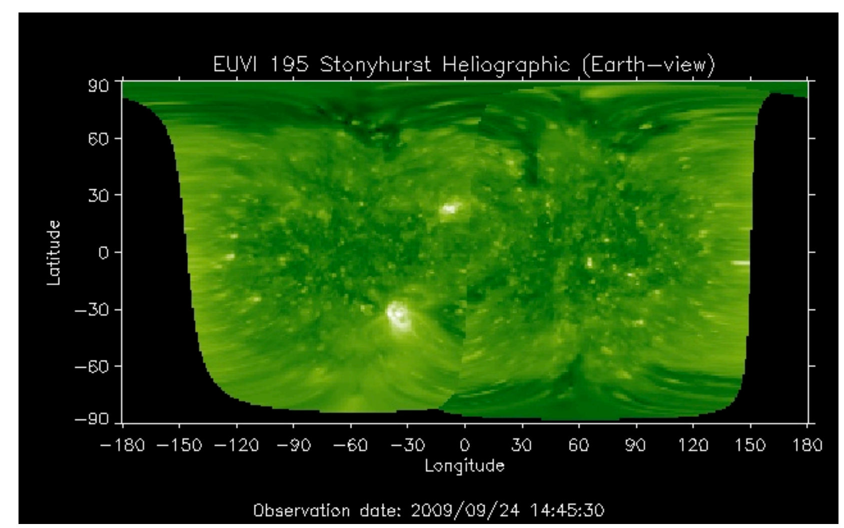
- Receiving telemetry from 4 stations in France, Germany, and Japan.
  - –About **80% coverage** for both spacecraft
  - –English 4.5 meter station dropped out in July 2009 due to low signal
  - –Difficult getting additional stations. No NOAA stations participating
  - –Using convolutional encoding instead of Turbo. Initially issues with Turbo licensing, currently with software implementation
- Space weather products generated in near-real time, and distributed *via* the Web

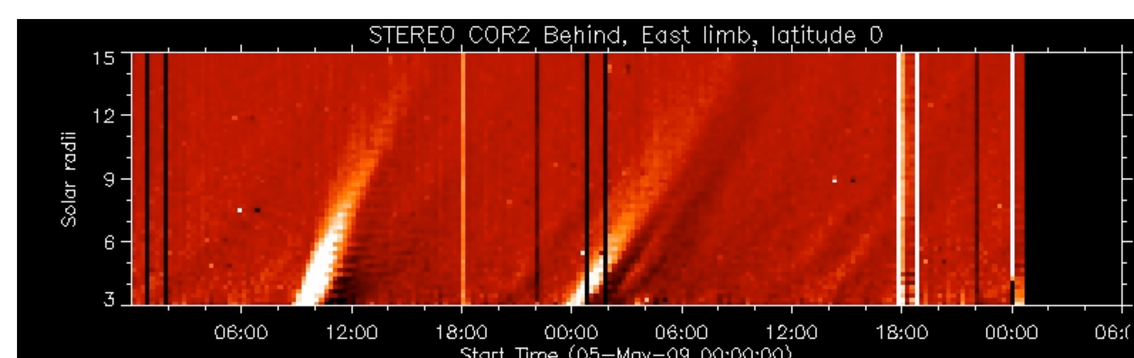












Scientific Data Usage

- SSC Website download rate: ~ 0.5 Tbyte/month
- Publications

Calendar year	Papers in refereed journals
2007	12
2008	56
2009 (so far)	120

- Two special, double issues of Solar Physics in 2009
  - total of 51 papers

Science Planning at SSC

- Relatively straightforward during the prime mission
  - Instruments plan essentially independently of each other
  - No resource conflicts that required SSC intervention
  - Data volume has been much higher than the 5 Gb/day requirement (*kudos to APL and DSN*)
- Coordination with other solar observatories organized using SOHO Joint Observing Program (JOP) system (going away in late summer 2010)
  - SOHO JOP database extended to include STEREO and other solar missions, rather than having a separate database.
  - Observation calendar on SSC website keeps track of when JOPs are run.
  - Only instrument that changes observing plan for JOPs is SECCHI.
- Largest coordination effort has been in planning for the lower telemetry rates during the extended mission
  - APL has added telemetry rates not originally implemented on spacecraft

STEREO downlink rates

- Downlink rates drive:
  - realtime rates
  - sampling rates
  - resolution (time, space)
  - use of SSR buffers
- More detail in Science Operations Plan
- Test of 240, 120 kbps on B, 2009/11/30

Rate (kbps)	Ahead	Behind
720	2007/01/22	2007/01/22
480	2008/10/13	2008/09/15
360	2009/08/17	2009/09/08
240	2010/04/26	2009/12/07
160	2010/09/13	2010/11/15
120	2011/04/11	2010/11/15
96	2011/09/26	2011/09/19
60	TBD	TBD
30	2012/08	2012/08

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Effects on Science (I)

- SWAVES
  - “Decoupled” operations (APL MOC as “bent pipe” for sending instrument commands to spacecraft, data to instrument teams and SSC) – “Has worked remarkably well”
    - “This has allowed the instrument teams to develop command and telemetry databases and to operate their instruments independently without interacting with a central project operations center. This also puts the burden of command verification on the instrument teams where it reasonably belongs.”
  - SWX beacon channel has been used for instrument housekeeping as well, allowing rapid alerts to instrument teams of anomalous behavior

Effects on Science (II)

- SECCHI
  - Responsiveness of the APL MOPs team has been excellent, for example when support is needed to staff additional tracks to recover from anomalies, and when planning special maneuvers for calibration purposes.
  - The particulate and organic cleanliness has been good, except for the increased number of particles in the FOV of the telescopes – but they have not impacted the Level-1 science
  - Weekly telecon has enabled good communications between all the ops teams so that the remote POCs concept has been successful.
  - Bill Thompson's overall leadership at the SSC is excellent – meeting summaries, calendar, web site and products, etc.

Effects on Science (III)

- PLASTIC
  - The stored command buffer on the spacecraft has reduced cost by not requiring MOC staff for command uploads, and enabled command delivery outside of spacecraft contacts.
  - The health and safety software in the IDPU that was written for PLASTIC by Microtel has been very effective. The automatic "safing and recovery" procedures for thruster operations have minimized data loss. This has positive implications for Solar Probe and other missions where instrument autonomy will be important.
  - Realtime (beacon) housekeeping and science data enable instrument teams to perform health and safety checks on every pass and quickly respond to anomalies.

Effects on Science (IV)

- IMPACT
  - Were able to commission, in some cases calibrate, almost all sensors during phasing orbits
  - Science during phasing orbits: observations of earth's plasma sheet and sheath, bow-shock-generated ion beams, ENA's from ring current, and the strongest SEP event so far
  - Rolls for MAG calibration allowed ongoing assessment of the stability of the MAG sensors
  - POCs used to upload software, on-board calibration and other adjustments (e.g. beacon mode MAG offsets), update new burst mode criteria, SWEA energy sweep limits, SEP suite calibration tables
  - Charging environment of anti-Sunward side of spacecraft not fully predicted
    - Internal charging in SWEA affects core electron distribution measurements

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Foreign interfaces (I)

- IMPACT
    - SWEA sensor fabricated at CESR (Toulouse, FR); SEPT sensor at Kiel (DE) with help from ESTEC (NL); SIT TOF electronics at MPS (DE)
    - "TAAs were obtained between APL and all these organizations. Main issues were initial confusion about how to deal with ITAR. When GSFC took over and coordinated all these cases, the process finally progressed so that work could proceed. GSFC's leadership role in this was critical for IMPACT."

Foreign interfaces (II)

- PLASTIC
  - Hardware components and characterization from University of Bern (CH), MPE (DE), and Kiel (DE)
  - ITAR regime was relatively new at Phase A, but APL was instrumental in obtaining TAAs, and GSFC provided key assistance in obtaining temporary export licenses
  - Project on multiple occasions disapproved or restricted foreign travel for technical meetings and instrument testing in Phase D, even though these travel commitments had been budgeted and approved at proposal stage. This impacted optimizing and calibrating the instrument response functions, affected manpower, and modestly increased US cost.

Foreign interfaces (III)

- SECCHI
  - RAL (UK) managed the HI effort and has done the majority of the calibration and instrument monitoring functions; CSL (BE) performed the optical design as well as HI level TV and vibration; initially Kiel and then MPS (DE) built the three SCIP doors; IAS/IOTA (FR) provided the EUVI mirror coatings and their calibration and LAM (FR) provided consulting.
  - Few instances where ITAR led to impediments were resolved; no ITAR issues during Phase E

Foreign interfaces (IV)

- SWAVES
  - PI is French
  - Observatory of Paris produced flight and ground hardware and software
  - All deliverables produced in a timely fashion
  - Paris group continues to provide data processing and scientific analysis, dissemination of data and results

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Requirements 2.C1 - 2.C3

- Determine the evolution of the CME mass distribution and the longitudinal extent to an accuracy of ± 5° as it propagates in the
  - C1 low corona
  - C2 upper corona
  - C3 interplanetary medium

Requirements C1 and C2

- Thernisien, Vourlidas, and Howard (2009, Solar Physics, 256, 111) forward model CME's in COR2
  - "graduated" cylindrical shell to mimic flux rope
  - applied to 28 CME's through 2008/08
  - Mean accuracy in ϕ of 4.3°, in θ of 1.8°
  - Also get speeds
- Recently applied to EUVI measurements as well

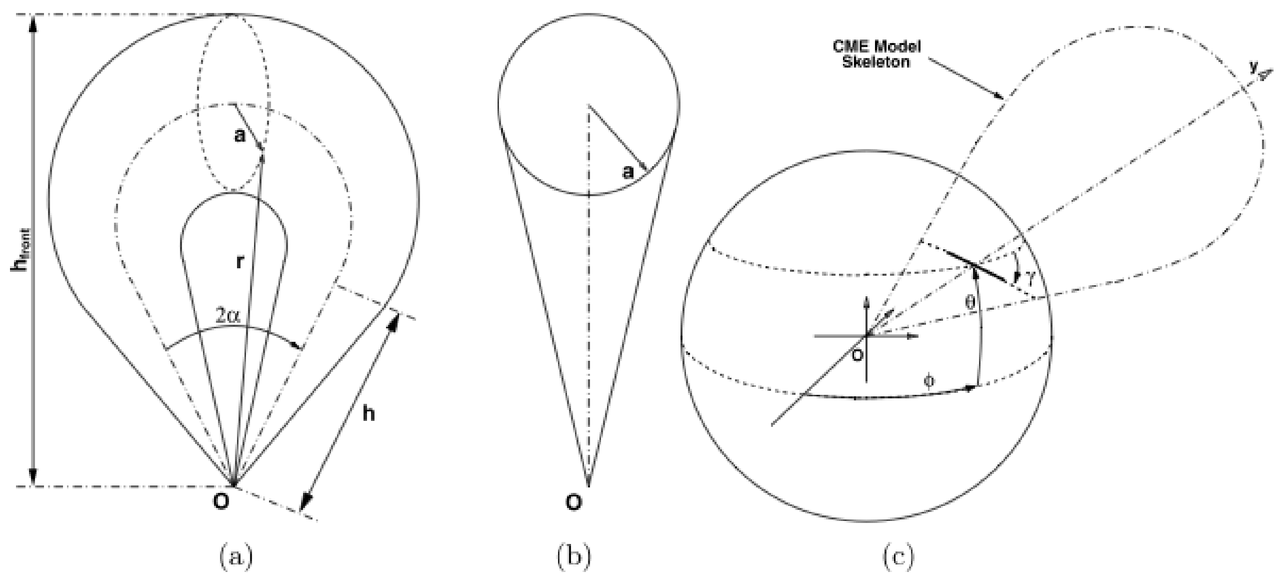
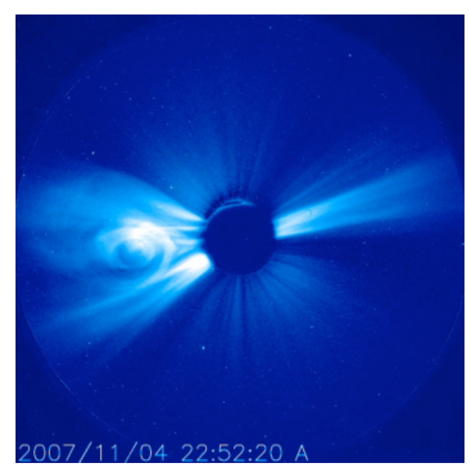


Figure 1 Representations of the Graduated Cylindrical Shell (GCS) model (a) face-on and (b) edge-on. The dash-dotted line is the axis through the center of the shell. The solid line represents a planar cut through the cylindrical shell and the origin. *O* corresponds to the center of the Sun. (c) Positioning parameters. The loop represents the axis through the center of the shell, ϕ and θ are the longitude and latitude, respectively, and γ is the tilt angle around the axis of symmetry of the model.

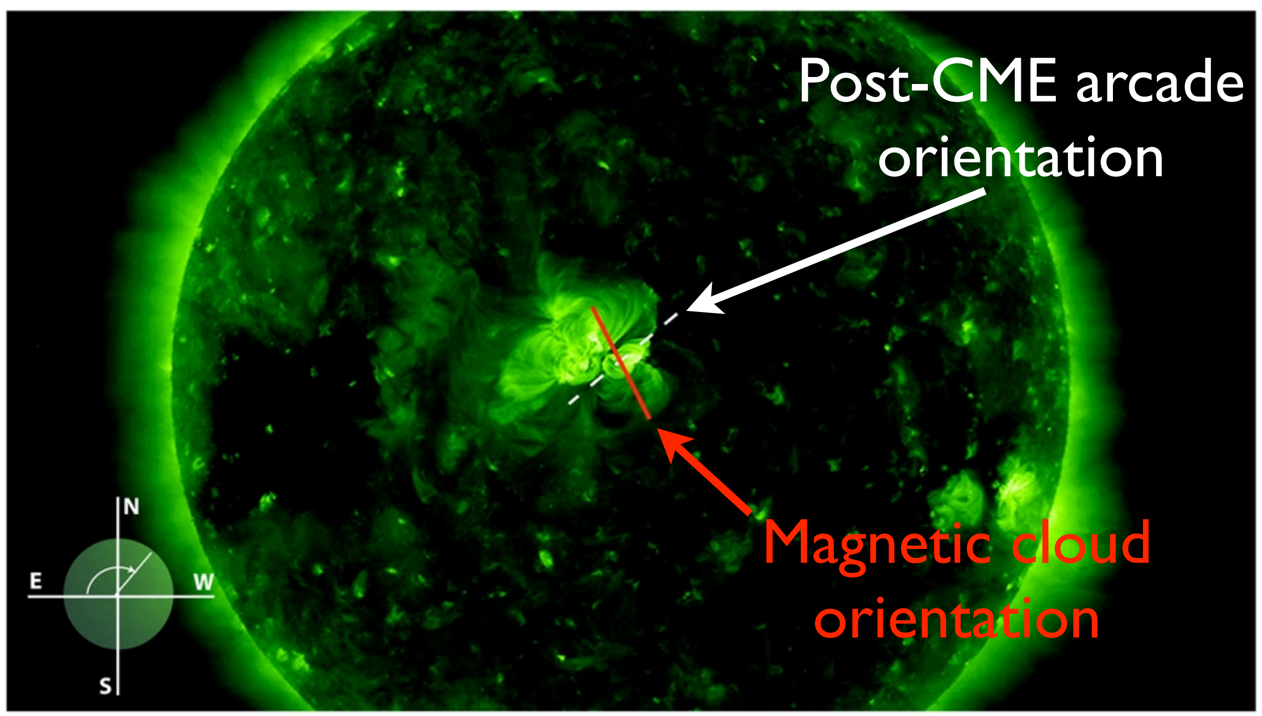


$$N_e(d) = N_e \exp\left[-\left(\frac{d-a}{\sigma_s}\right)^2\right],$$

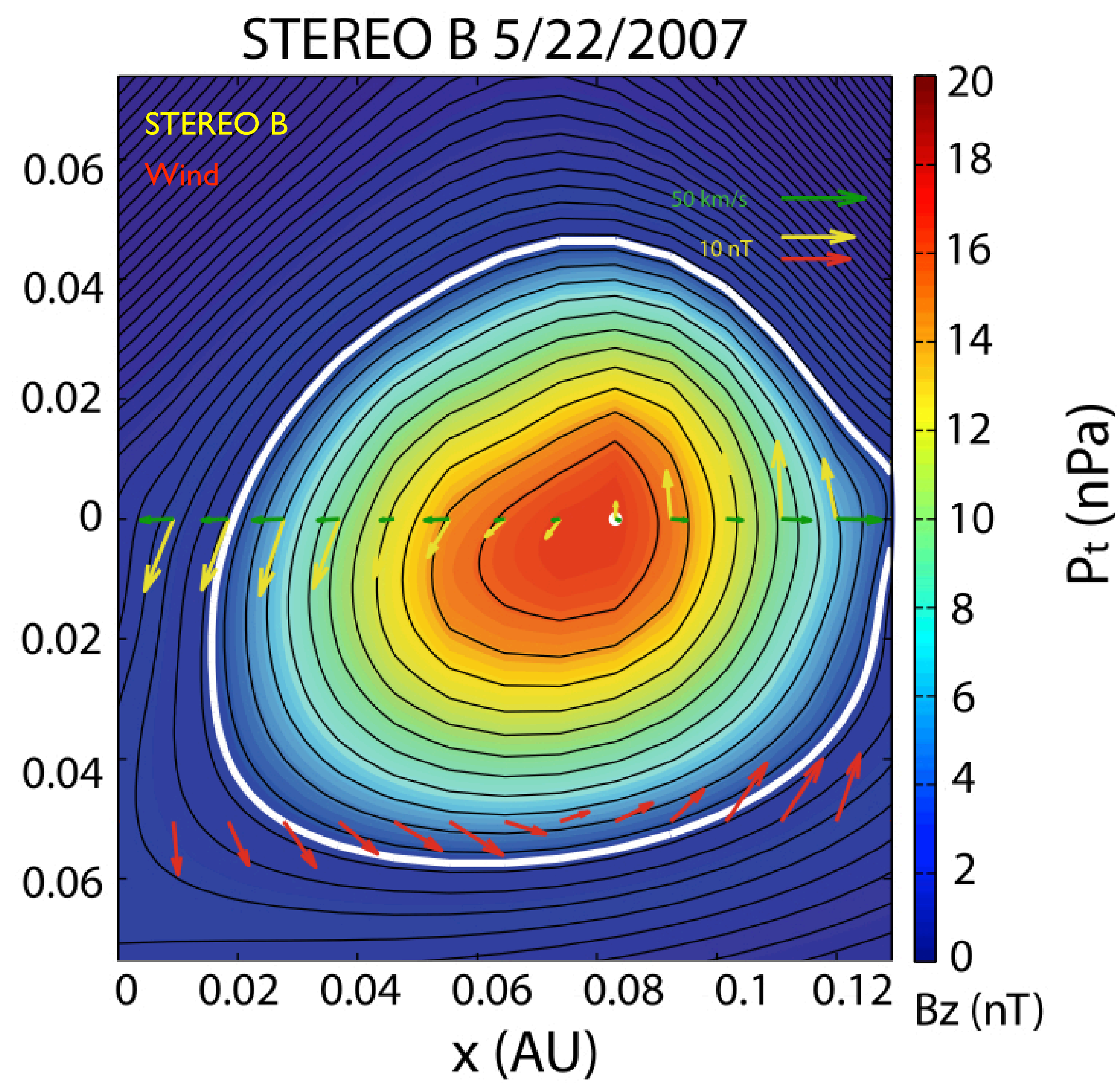
$$\text{with } \sigma_s = \begin{cases} \sigma_{\text{trailing}} & \text{if } d < a, \\ \sigma_{\text{leading}} & \text{if } d \geq a. \end{cases} \tag{3}$$

C.3

- Using solar wind plasma and magnetic field data from STEREO PLASTIC, IMPACT and WIND, Kilpua *et al.*(2009, Solar Physics, 254, 325) derive interplanetary magnetic cloud (MC) location and orientation

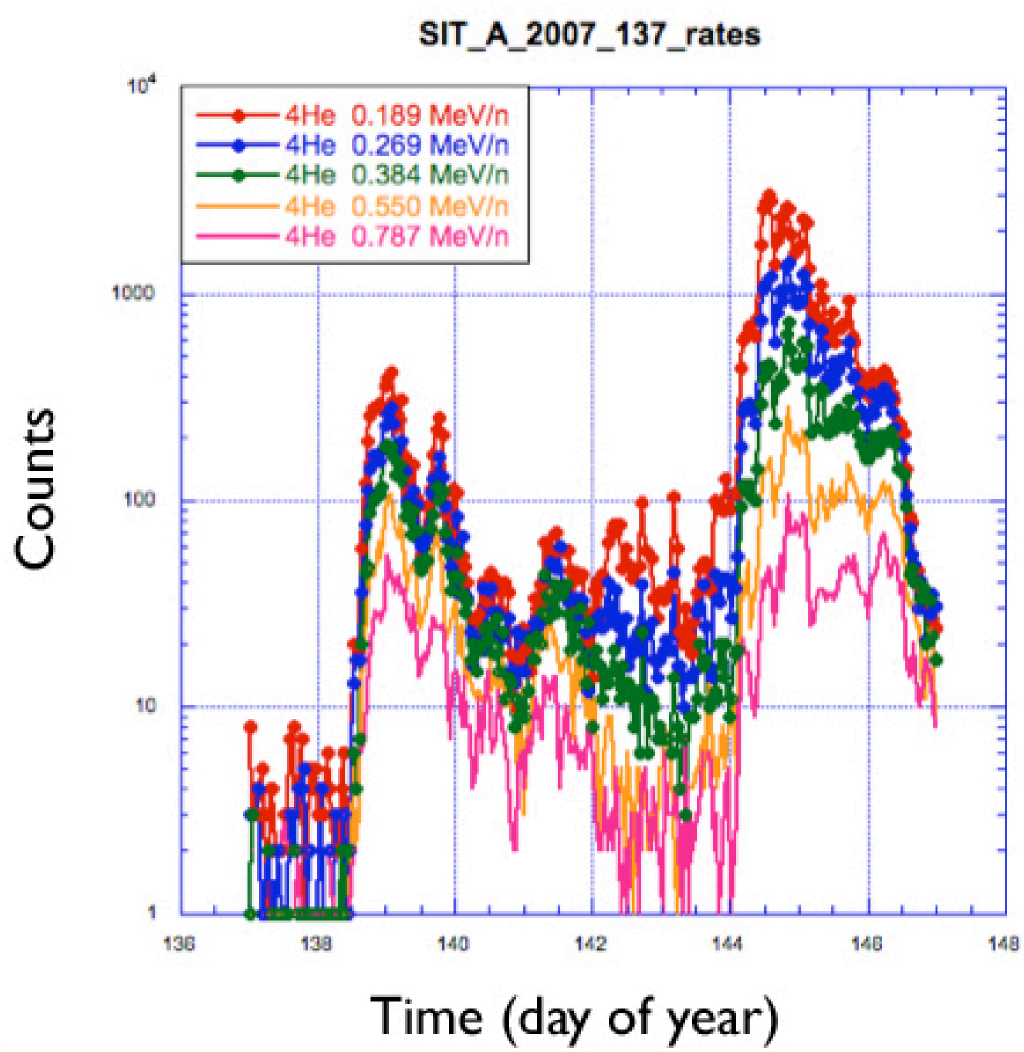


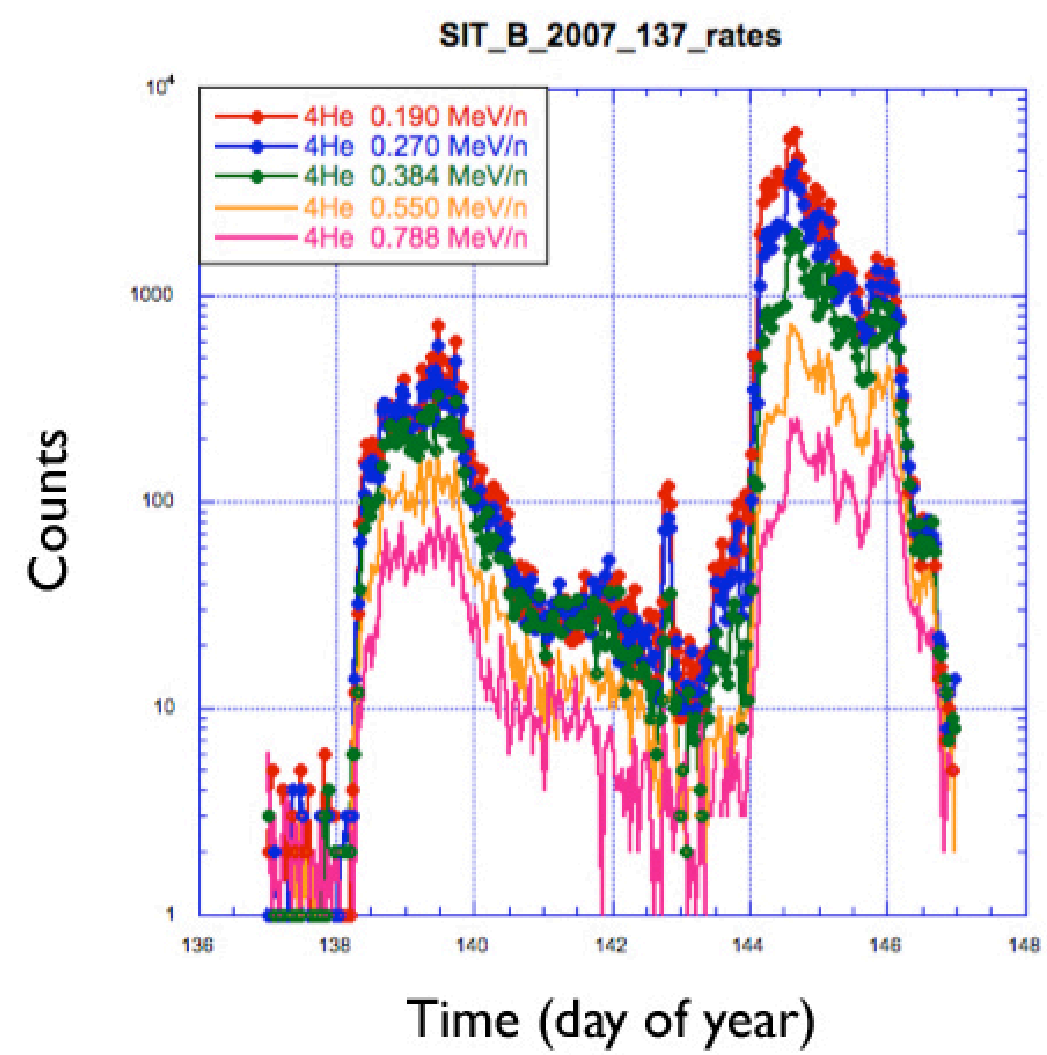
Combining remote sensing *(above)*_and multi-spacecraft in-situ measurements *(right)* makes it possible to satisfy the requirement.



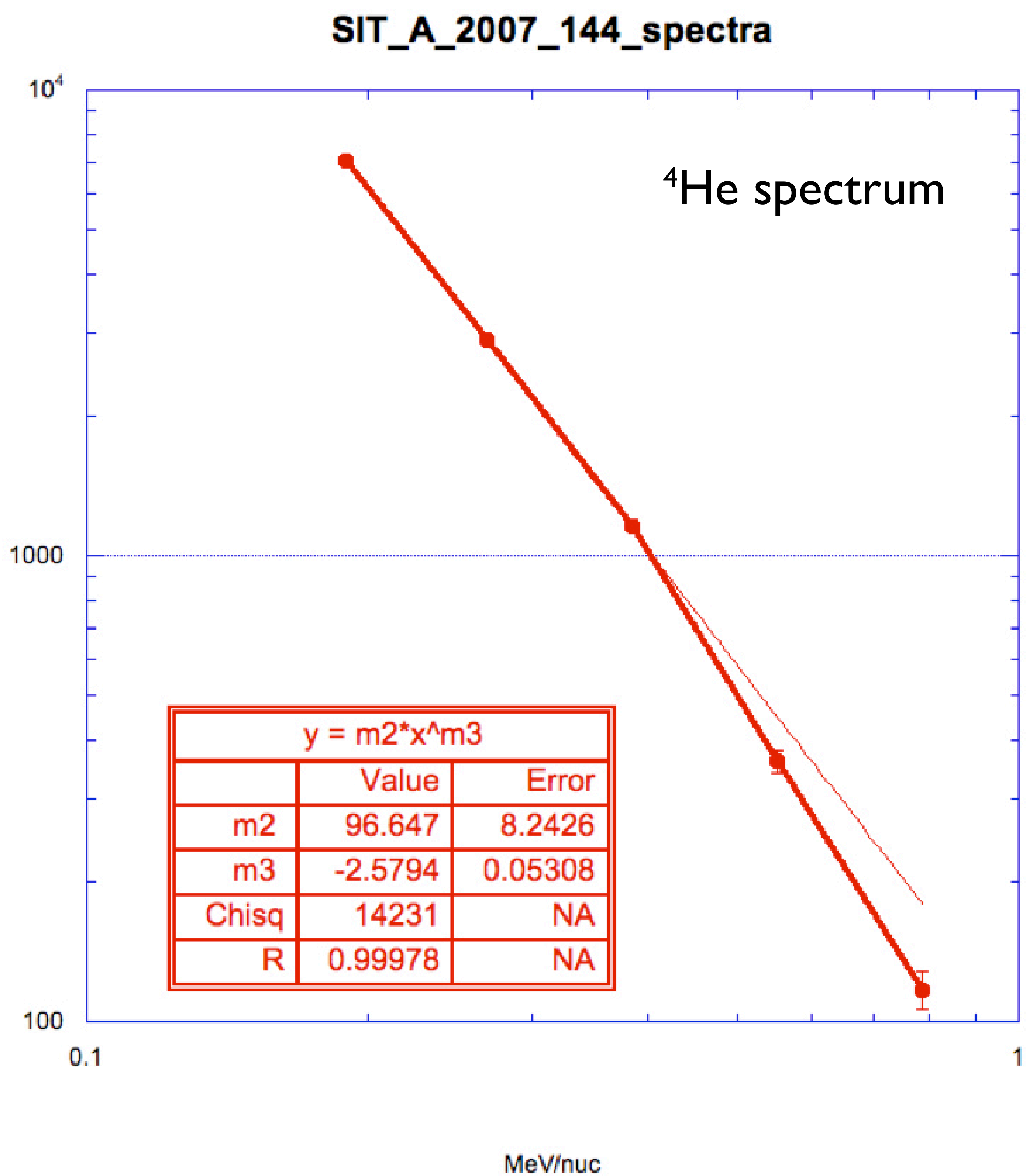
Requirement 3.F (I)

- "Develop distribution functions an accuracy of ±10% for electrons and/or ions with energies typical of solar energetic particle populations"
  - Bučík *et al.* (2009, Solar Physics, 259, 361) studied energetic ions in CIRs (probably seeded by SEPs) in 2007 May





Requirement 3.F (II)



- Count rate statistics are better than 10% when count rates are > 100, which is typical for SEP events
- Similarly for spectral indices when integration period is sufficiently long

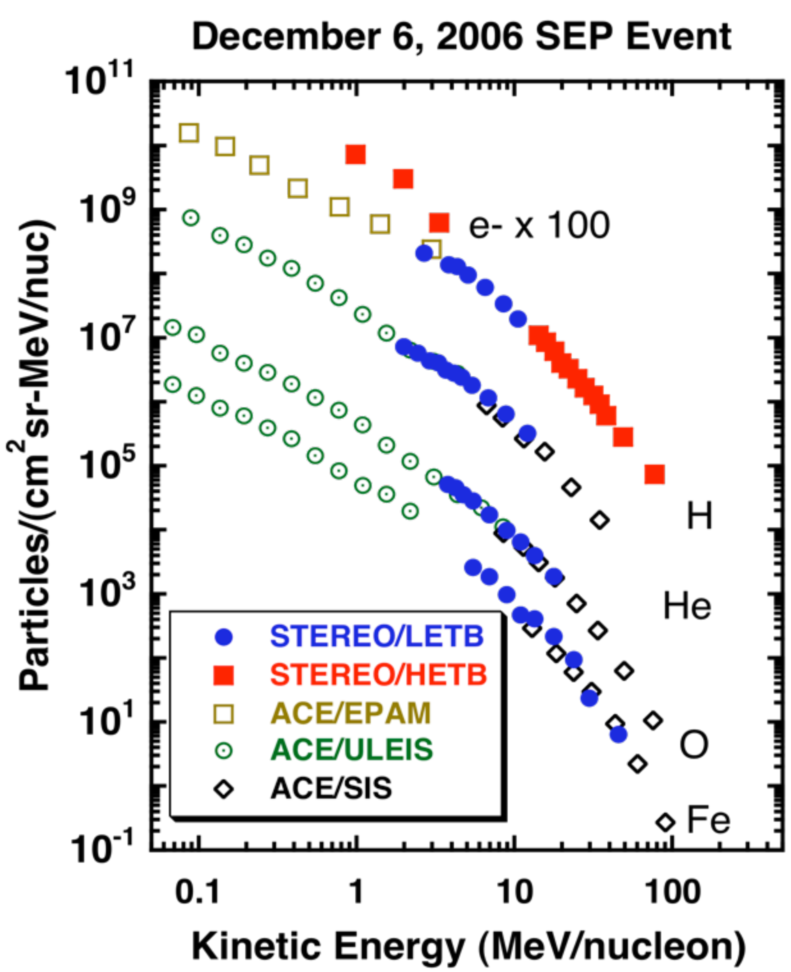
Requirement 3.F (III)

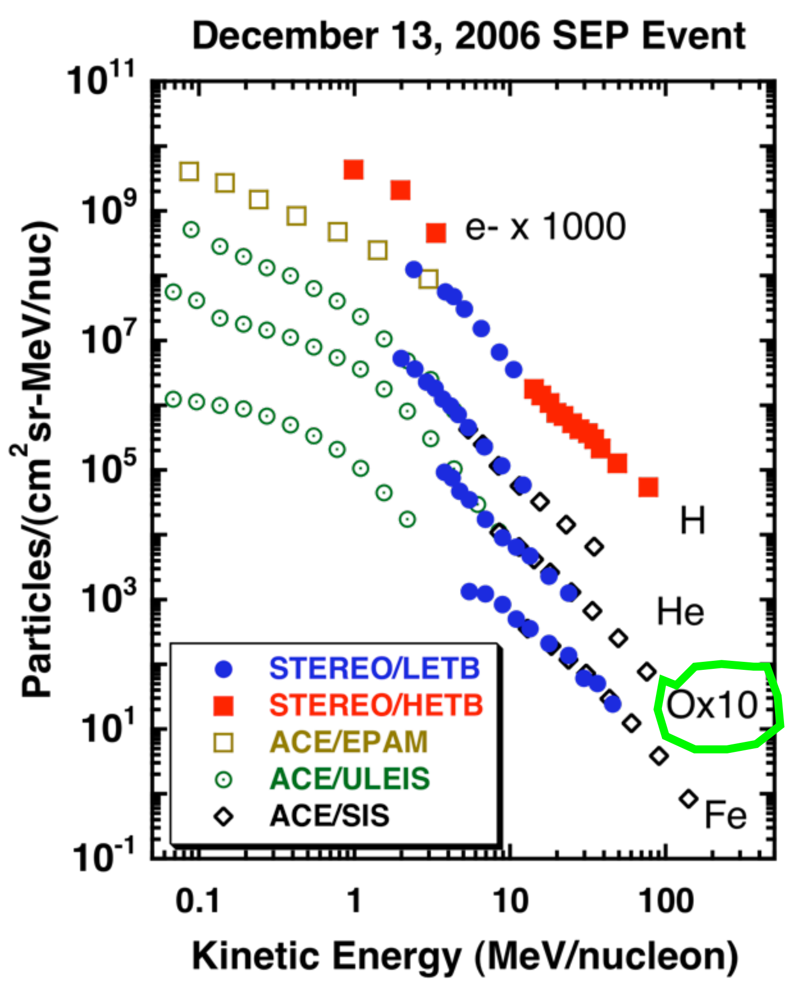
- Similar results for other CIRs in Mason *et al.* (2009, Solar Physics, 256, 393)
- Similar results for 2006 December 5 -14 events (Malandraki *et al.* 2009, ApJ, 704, 459): 4 large SEP events
  - STEREO spacecraft not well separated but still saw different p distributions on 2006 December 13 and 14 (von Rosenvinge *et al.* 2009, Solar Physics, 256, 443)
  - Composition results of Mewaldt *et al.* (2007, Space Sci. Rev., 136, 285) from 2006 December 13 event also have uncertainties < 10%

Requirement 3.G (I)

- "Location of particle acceleration in the low corona to within 300,000 [500,000] km in radius and in interplanetary space to within 20° [40°] in total longitude"

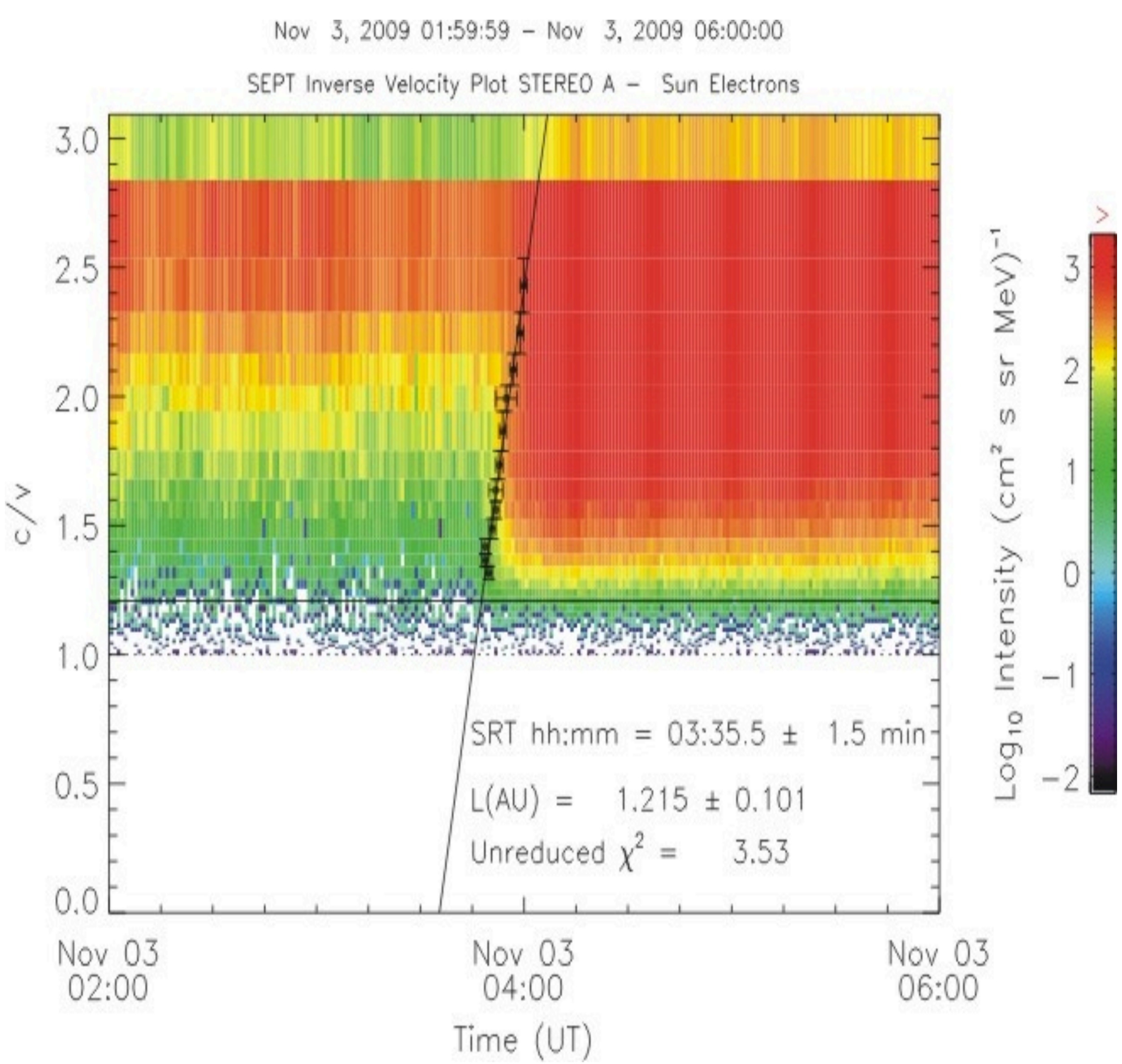
- Spacecraft not yet well separated during 2006 December events
  - Markedly different heavy ion composition in two of the events





Requirement 3.G (II)

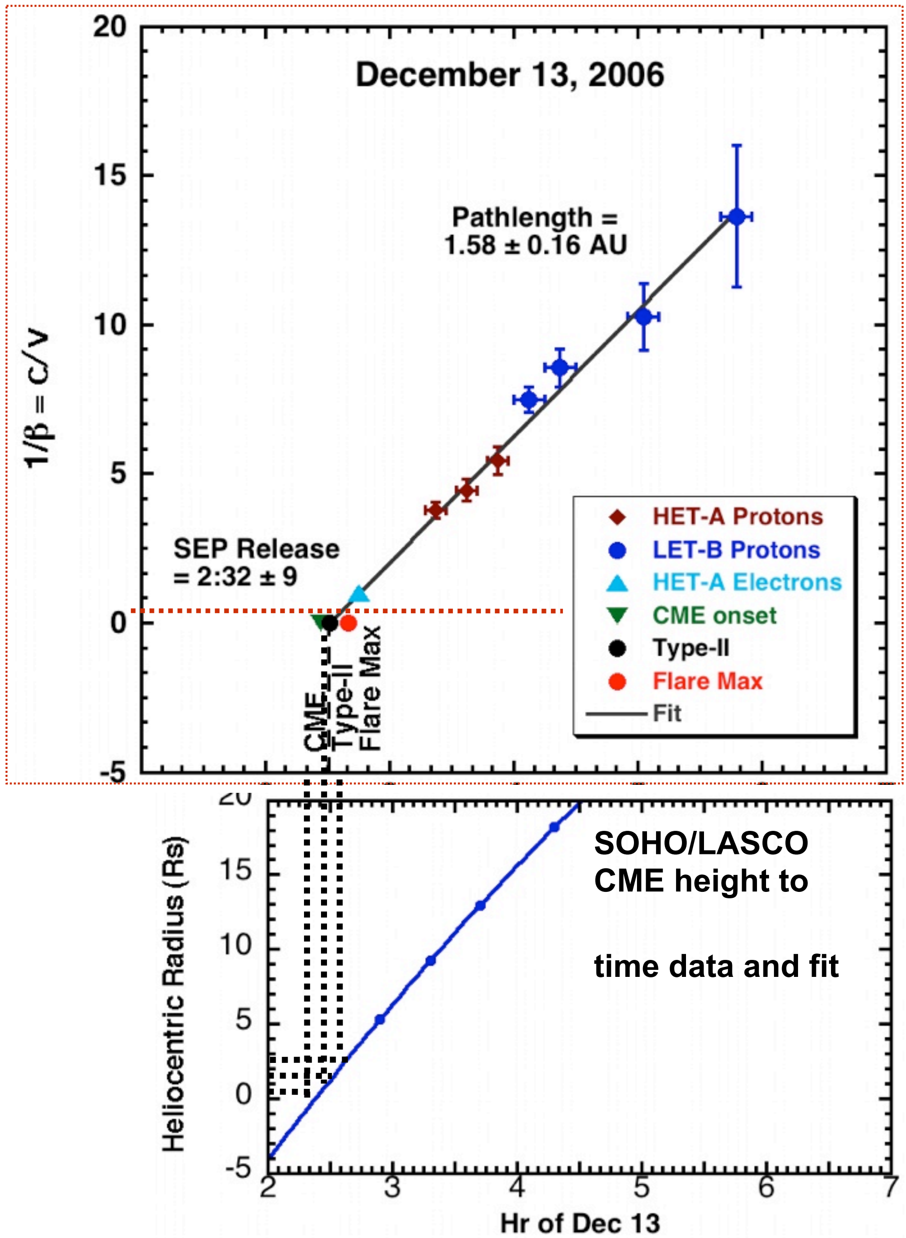
- Recent (2009 November 3) SEP event



- Onset time vs. inverse velocity (*cf.* Lin *et al.* 1981) provides an estimate of e^- injection time:
  - L = (1.2 ± 0.1) AU
  - t_0 = 03:44 UT ± 2 min
  - +8 min delay to match SWAVES
  - ~12 min delay compared to Type III

Requirement 3.G (III)

- Where and when SEPs are released near the Sun?



- Plotting onset times for protons with various energies versus 1/β reveals the SEP release time near the Sun
- The SEP release time in this event is consistent with either the X-ray flare onset or with shock acceleration by a CME driven shock, provided the shock forms low in the corona (within ~2 R_S of the solar surface)

Requirement G.3 (IV)

- Demonstrated capability to measure electron injection times to ±2 min accuracy
- Demonstrated capability to measured ion release times to ±9 min accuracy and release location to ±1.6 R_S (Mewaldt *et al.*, in preparation)
- Measured centroid of SEP-related ENA origin to within ±2° and discovered new method to track SEP acceleration/transport in the high corona using ENAs (Mewaldt *et al.* 2009, ApJ, 693, L11)
- Located origin of small SEP event with 3 separated spacecraft (Wiedenbeck *et al.* 2009, Solar Wind 12, *in press*)

So how did we really do?

SCIENTIFIC OBJECTIVE		MEASUREMENT REQUIREMENT	
3	Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium	F.	Develop distribution functions to an accuracy of ± 10% for electrons and/or ions with energies typical of solar energetic particle populations
		G.	Location of particle acceleration in the low corona to within 300,000 km [500,000 km] in radius and in interplanetary space to within 20 degrees [40 degrees] in total longitude
4	Develop a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind	H.	Obtain a time series of the solar wind temperature accurate to ±10 [30]% at two points separated in solar longitude
		I.	Obtain a time series of the solar wind density accurate to ± 10[30] at two points separated in solar longitude
		J.	Obtain a time series of the solar wind speed accurate to ± 10 [30]% at two points separated in solar longitude
		K.	Measure global magnetic field topology near the ecliptic by determining the magnetic field direction to ± 10 degrees.

- We really have met 3.F
- Demonstrated the capability to meet 3.G as soon as the Sun cooperates

Presentations

- Mission overview [15 m]
- Systems and engineering aspects of ops [45 m]
  - How these affected science [10 m]
- Foreign partnerships/issues [15 m]
- Science overview [20 m]
  - How did we get to full completion of (nearly all) Level-1 requirements [2 examples]
  - 2 counterexamples [10 m]
- Financial overview [10 m]
- Quick summary [10 m]

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- Financial overview [10 m]
- Quick summary [10 m]

Summary

- Mission is scientifically successful
  - but we wait on the Sun to make life more interesting
  - while continuing to publish papers of signficance
- Lessons learned
  - Spacecraft
  - Ground system
  - Instruments

Lessons Learned (Spacecraft and Ground System)

- "Value-based" data return works well
  - reduces operations staffing and DSN scheduling overhead
  - returns well over targeted, average data volume
- Instrument responsibility for instrument commanding, health and safety works well
  - saves on MOC complexity, operations staffing
  - reinforces *SOHO* experience

Lessons Learned (Instruments - I)

- ITAR not a serious issue during Phase E if handled by GSFC project management in Phases A-D
- Project management needs to take Phase A-D travel for consultation with foreign partners seriously if scientific success is to be assured within Phase E funding
- Instrument commanding by teams works well
- SSC and PI sites have been effective in disseminating data, as evidenced by the publication record

Lessons Learned (Instruments - II)

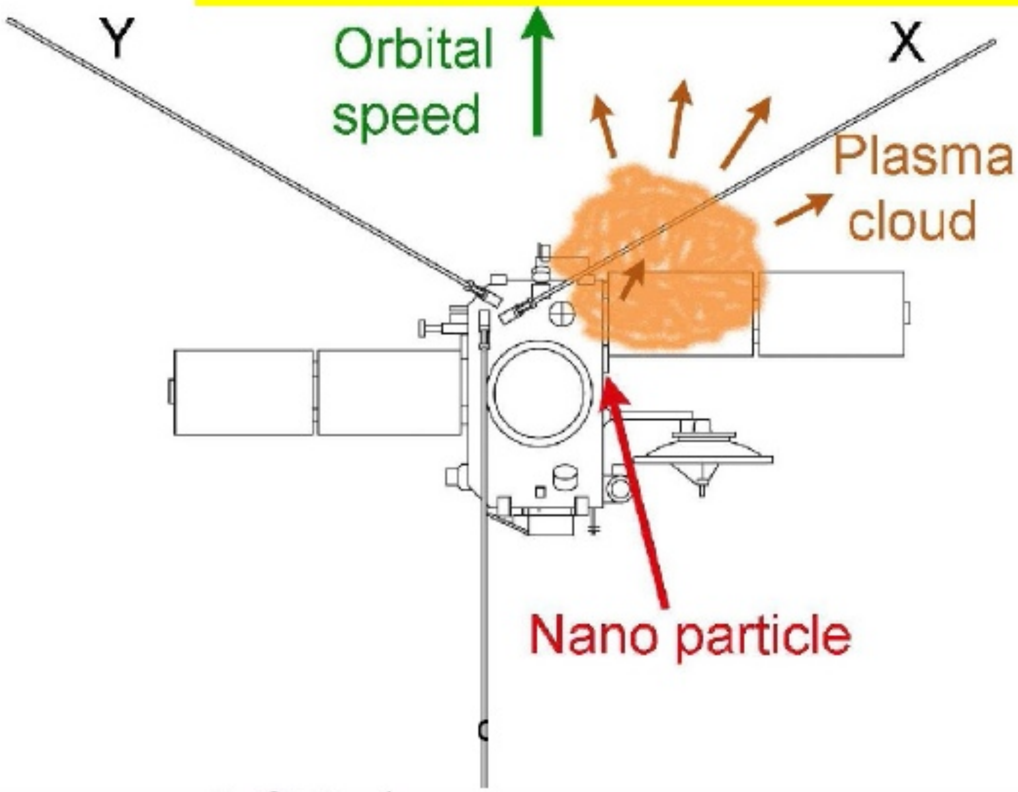
- Requirement 3.G teaches us to be humble in how we write requirements:
    - We can't schedule the Sun
    - We can't even assume this cycle will be like the previous four

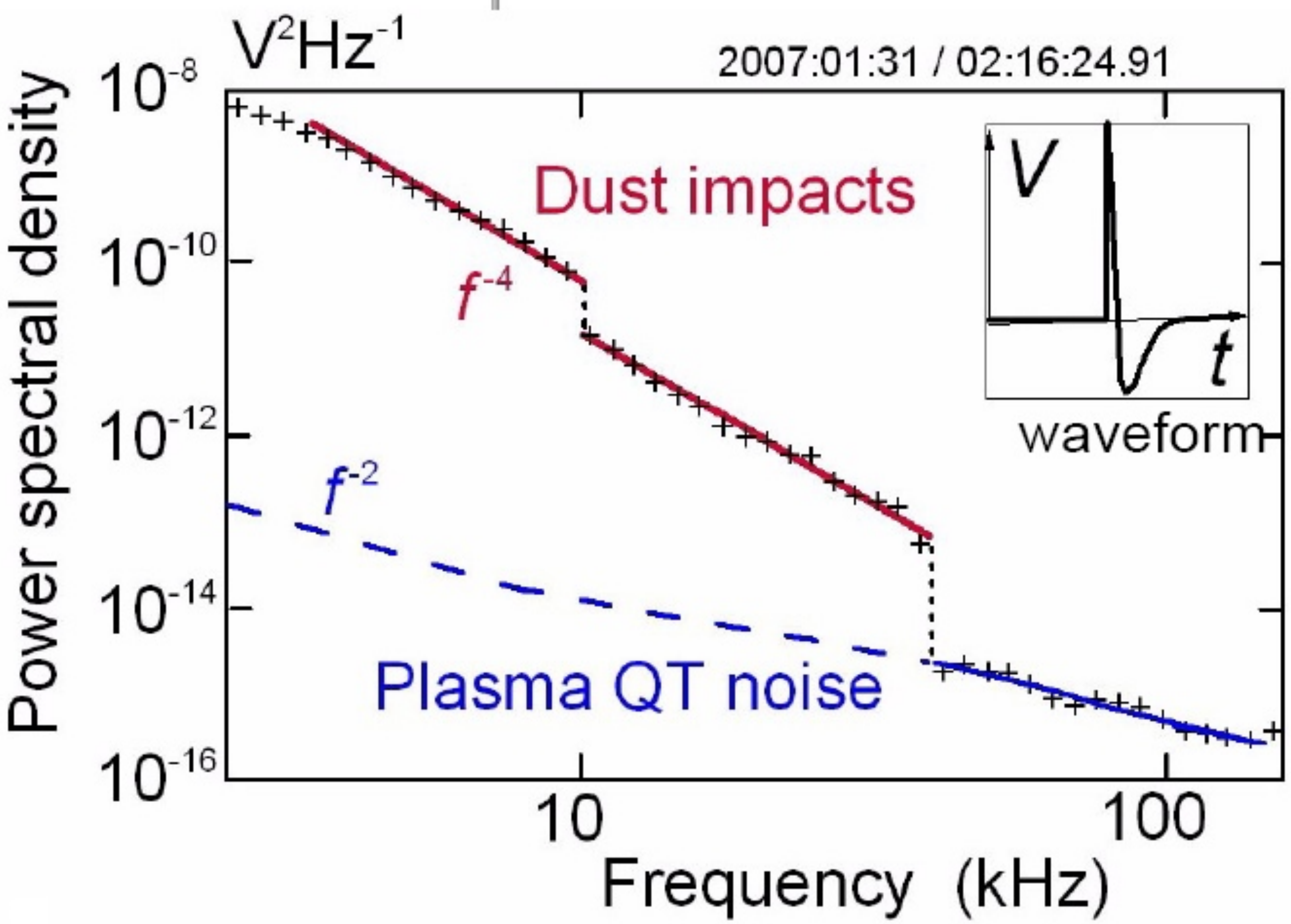
Bottom Line

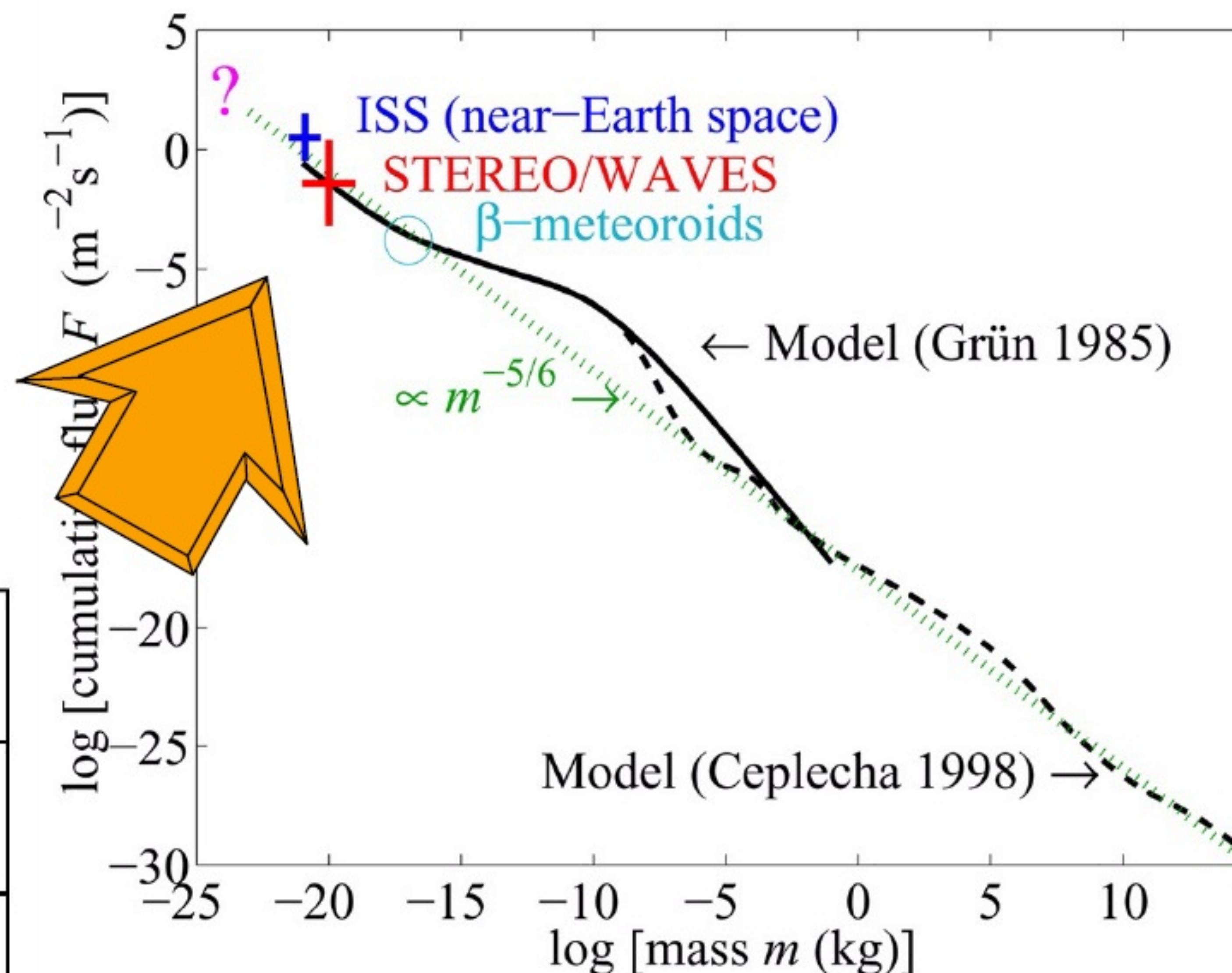
- STEREO is a successful mission
- We only wait for the Sun to make it a spectacularly successful one

Supporting material

STEREO in solar wind at 1 AU detects nano dust



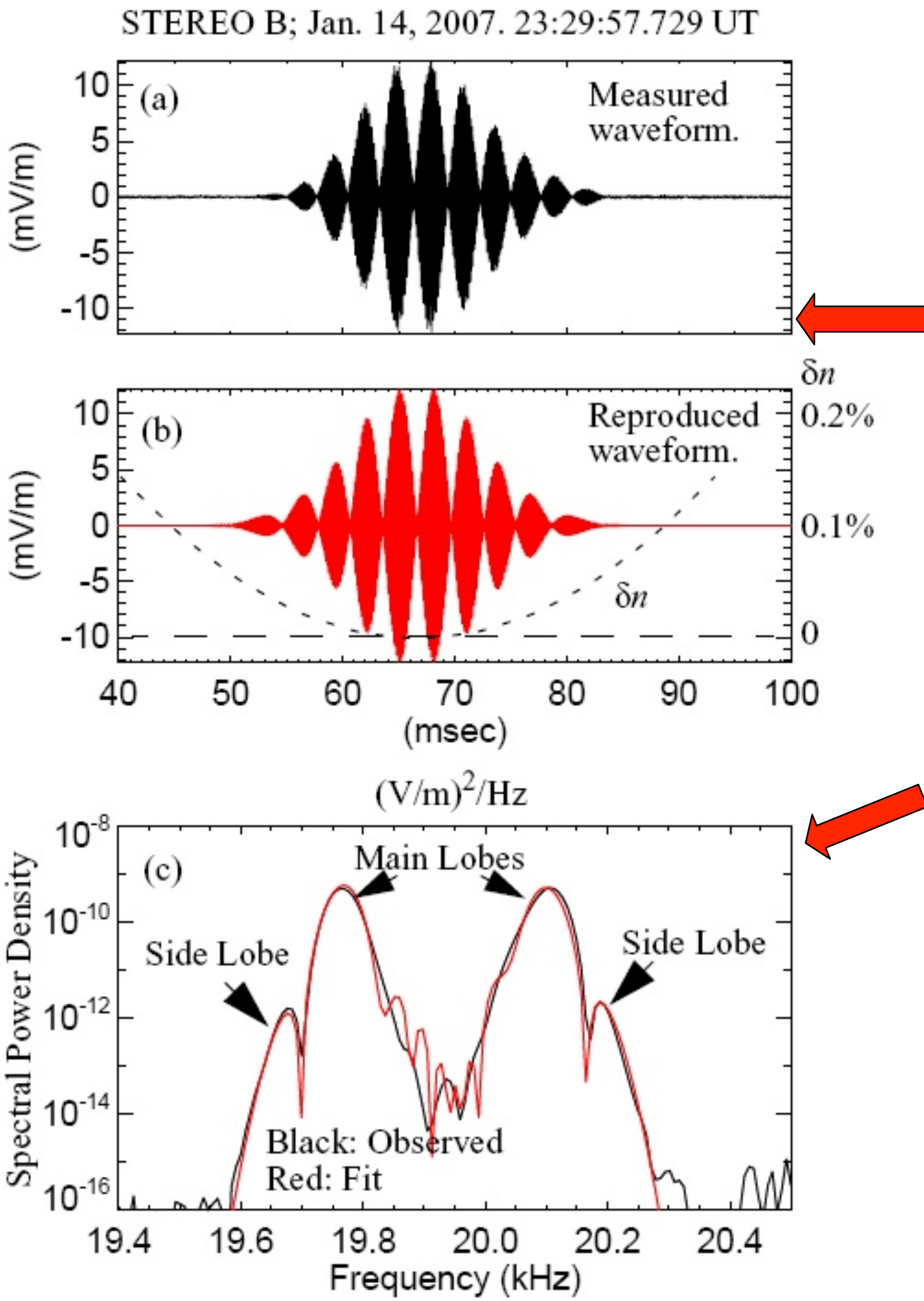




Meyer-Vernet, Maksimovic et al., Solar Phys. 256, 463 (2009)

Type III radio burst associated Langmuir waves (in situ)

Longer duration of the Time Domain Sampler (TDS) events (up to 130 msec possible compared to ~16msec on WIND) has greatly improved our knowledge of these waves



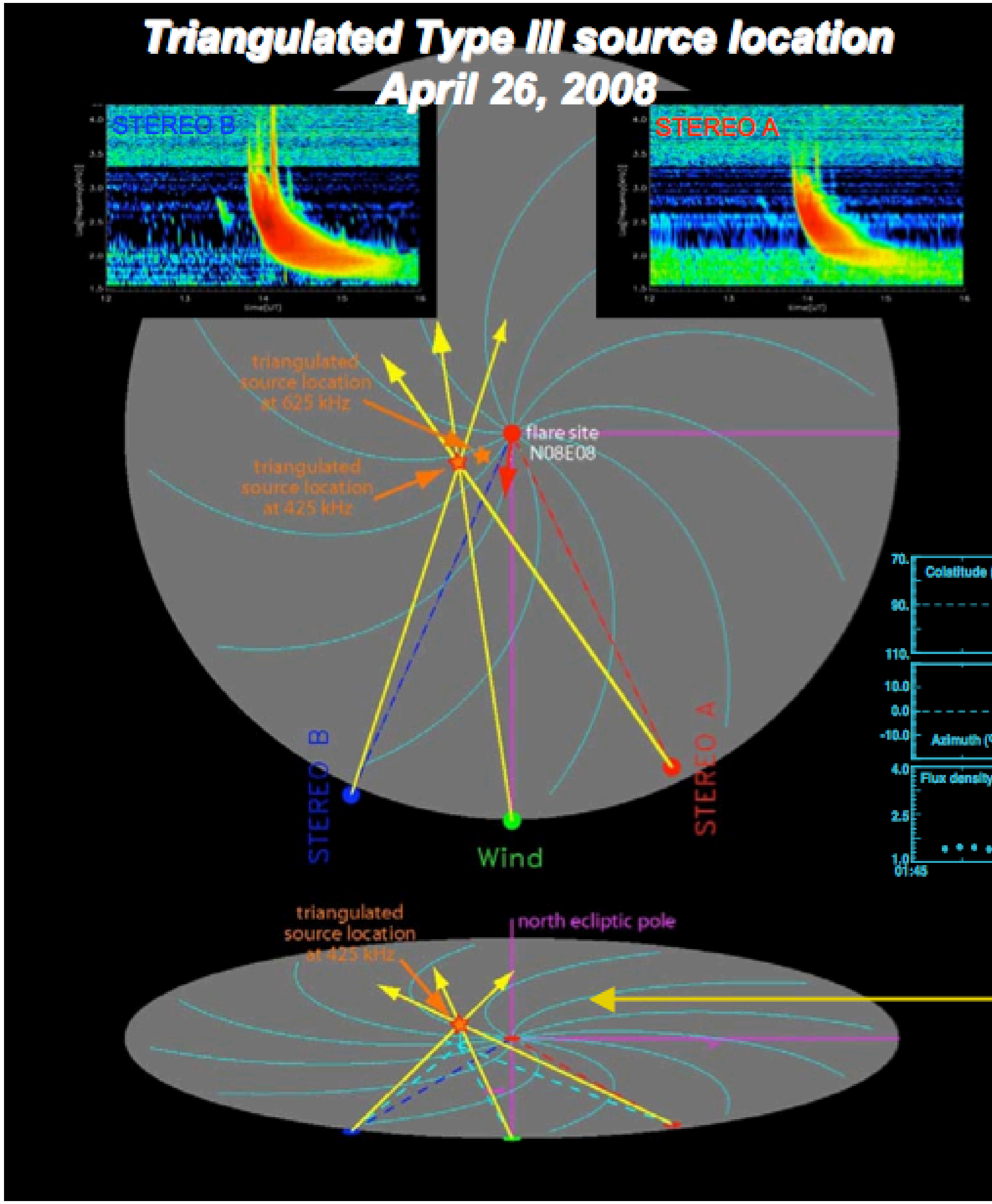
Various models :

- Observations and simulation of localized eigenmodes trapped in a parabolic density fluctuation (Ergun et al. 2008, Malaspina et al. 2008, Zaslavsky et al. 2009)

- Direct evidence for three-wave coupling (Langmuir and Ion acoustic waves) : Henri et al. 2008, 2009

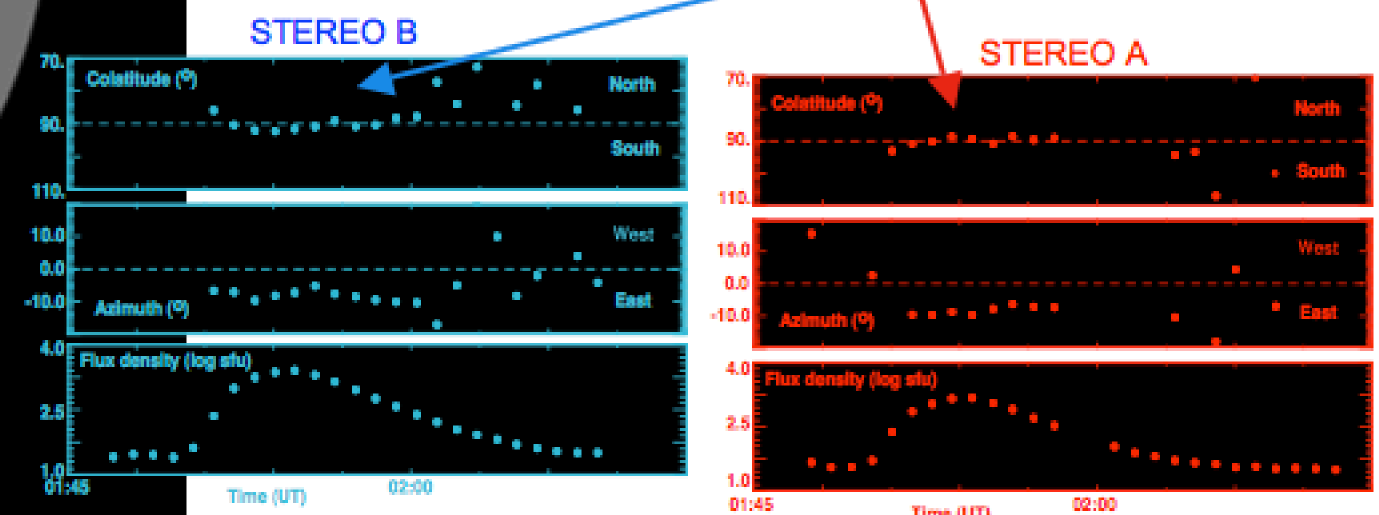
- These observations are key to understanding the radio burst emission processes

Interplanetary Radio Source Locations from STEREO (and Wind)



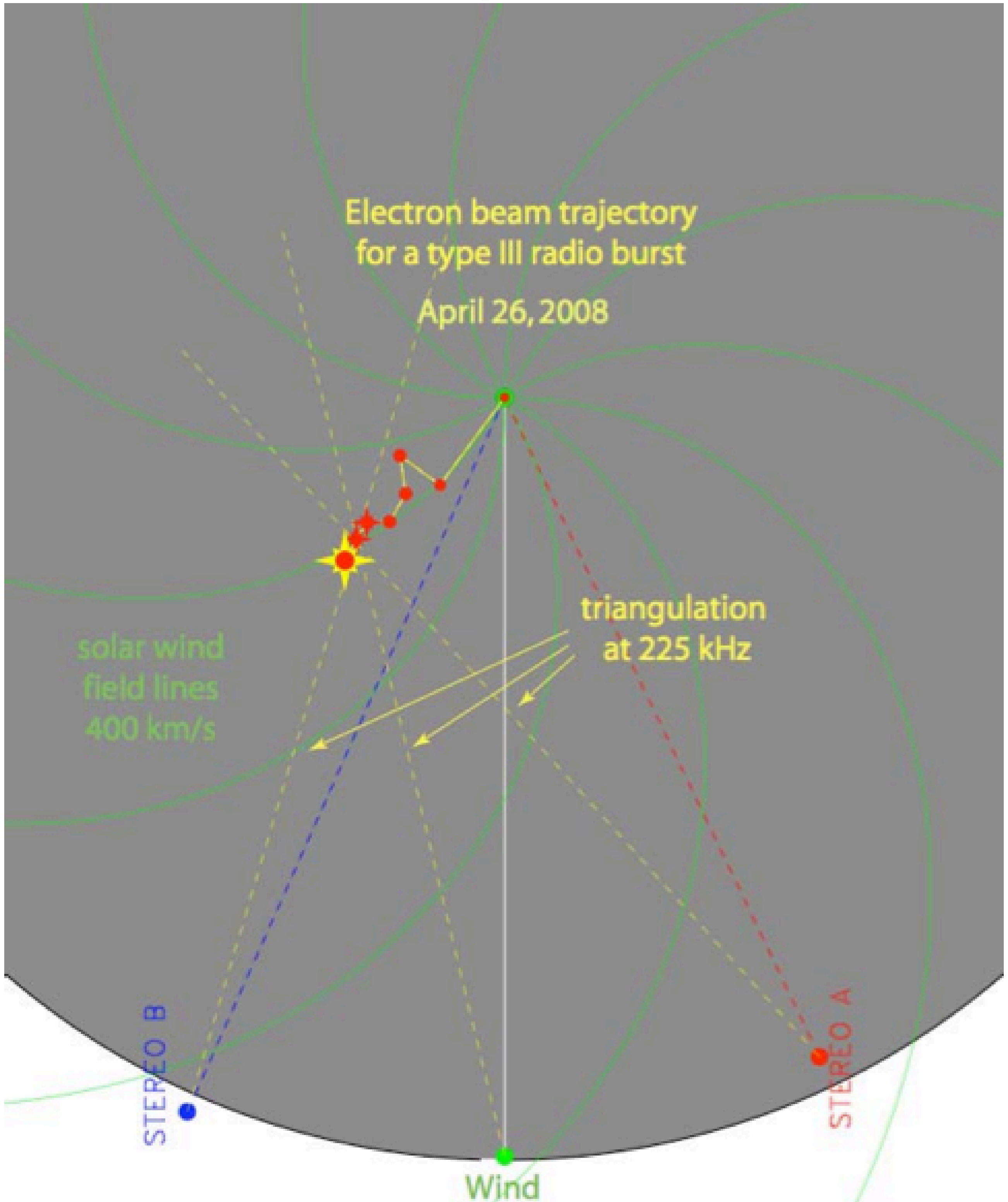
• CME-driven shocks and electron beams from the Sun produce radio emissions at successively lower frequencies due to the decrease in the interplanetary plasma density

• Azimuth and elevation angles to the remote radio source are deduced at each observing frequency by measuring the auto and cross correlation voltages on the 3 quasi-orthogonal SWAVES antennas



• Triangulation of these line-of-sight measurements from the STEREO s/c (and Wind) then give the 3D location of the radio source at each observing frequency

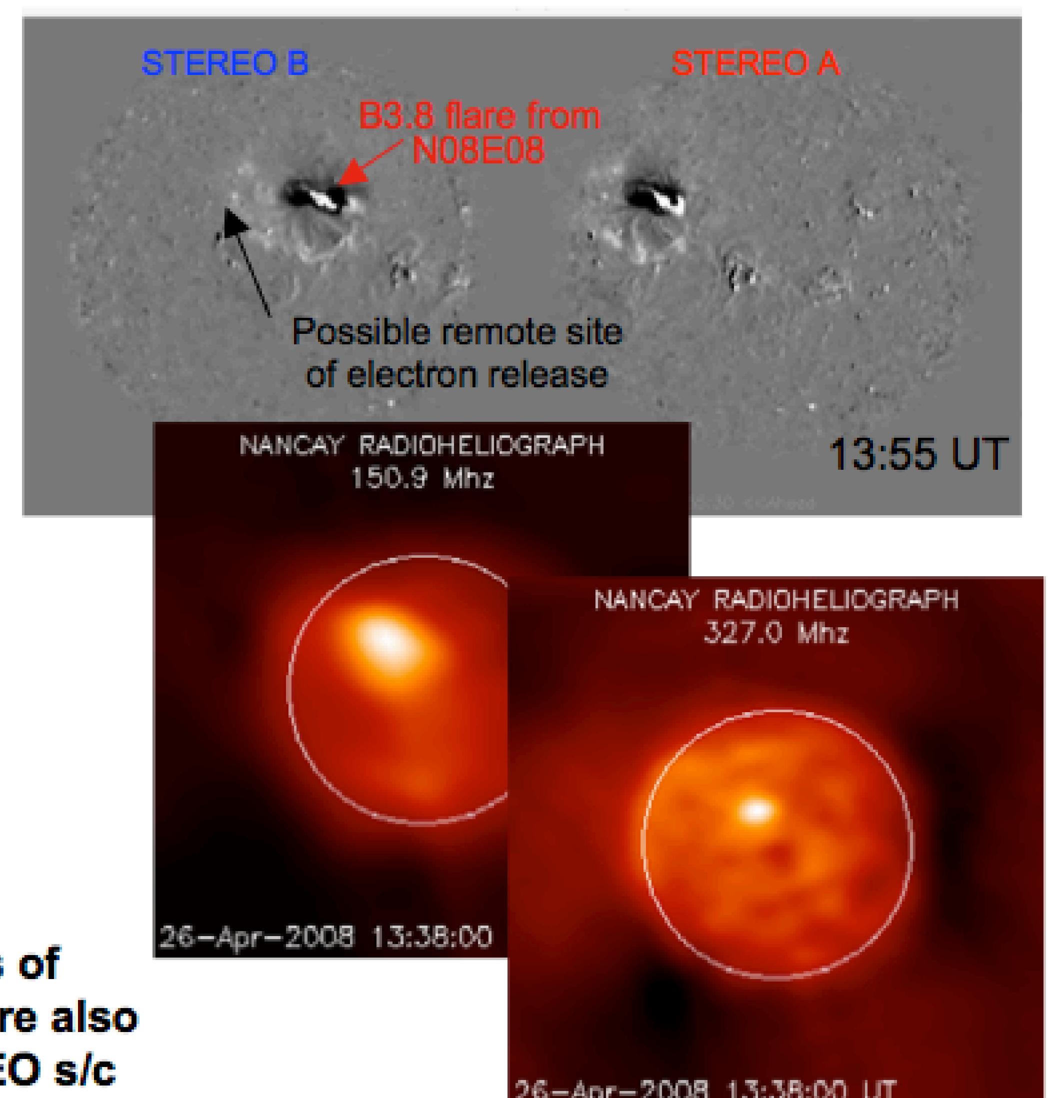
Interplanetary Radio Source Locations from STEREO (and Wind)



• The 3D source locations, at multiple frequencies, give the spatial path of the electron beam or the path of the CME shock through the IPM.

• This trajectory is projected back to identify the origin in specific solar surface features (such as active regions and solar radio sources)

• Its projection outward reveals the spatial connection between those solar features and the in-situ (particles, plasma waves, etc) observations



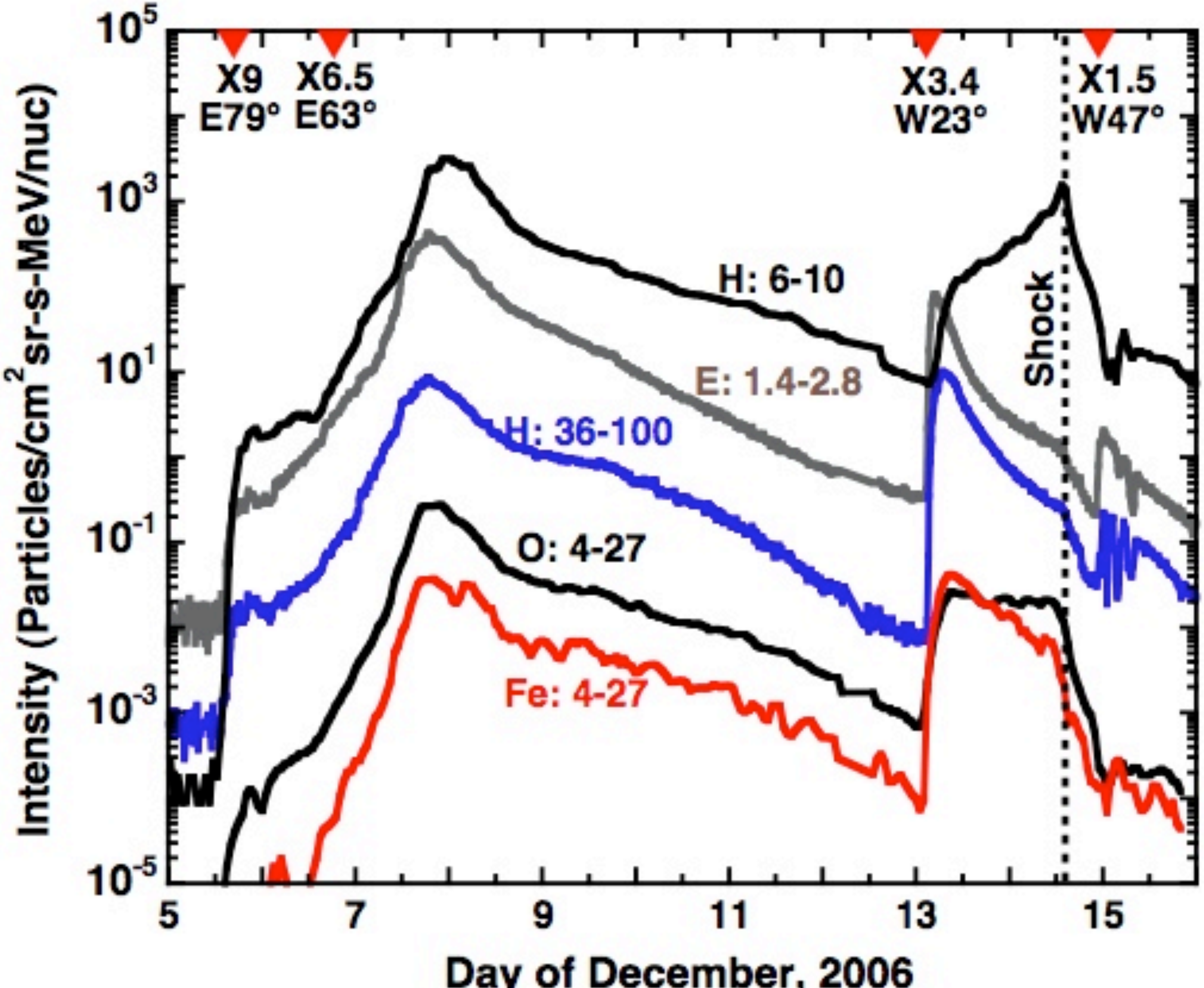
• The radio characteristics of the source, such as the radio beaming pattern (Solar Physcis 259, 255, 2009), the characteristics of radio wave propagation through the IPM, and the IPM density profile are also deduced from these remote radio measurements made by the STEREO s/c

SWAVES Experiment

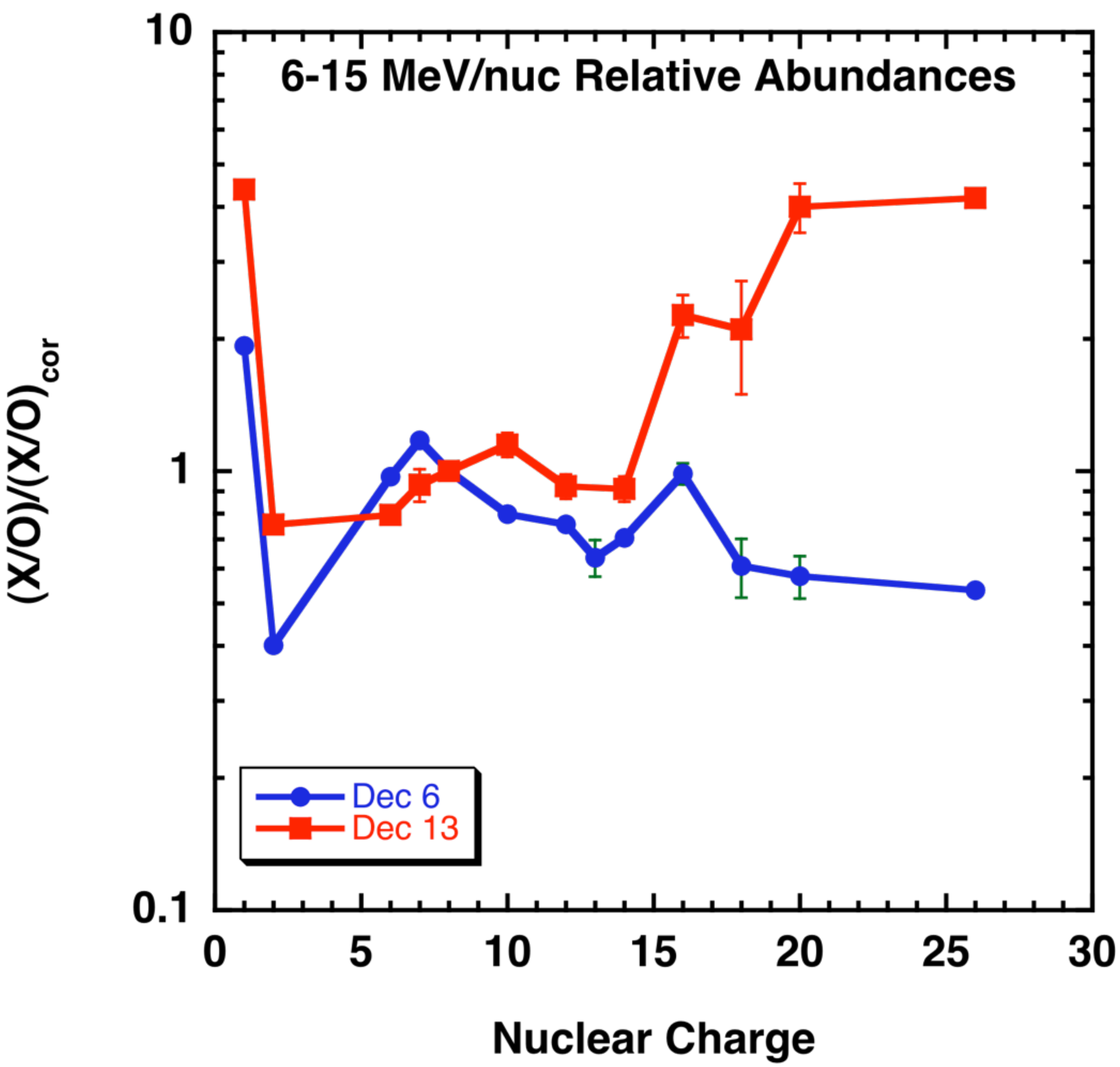
SEP Contributions to the STEREO Prime Mission Review

11/5/09

The December 2006 Solar Energetic Particle Events



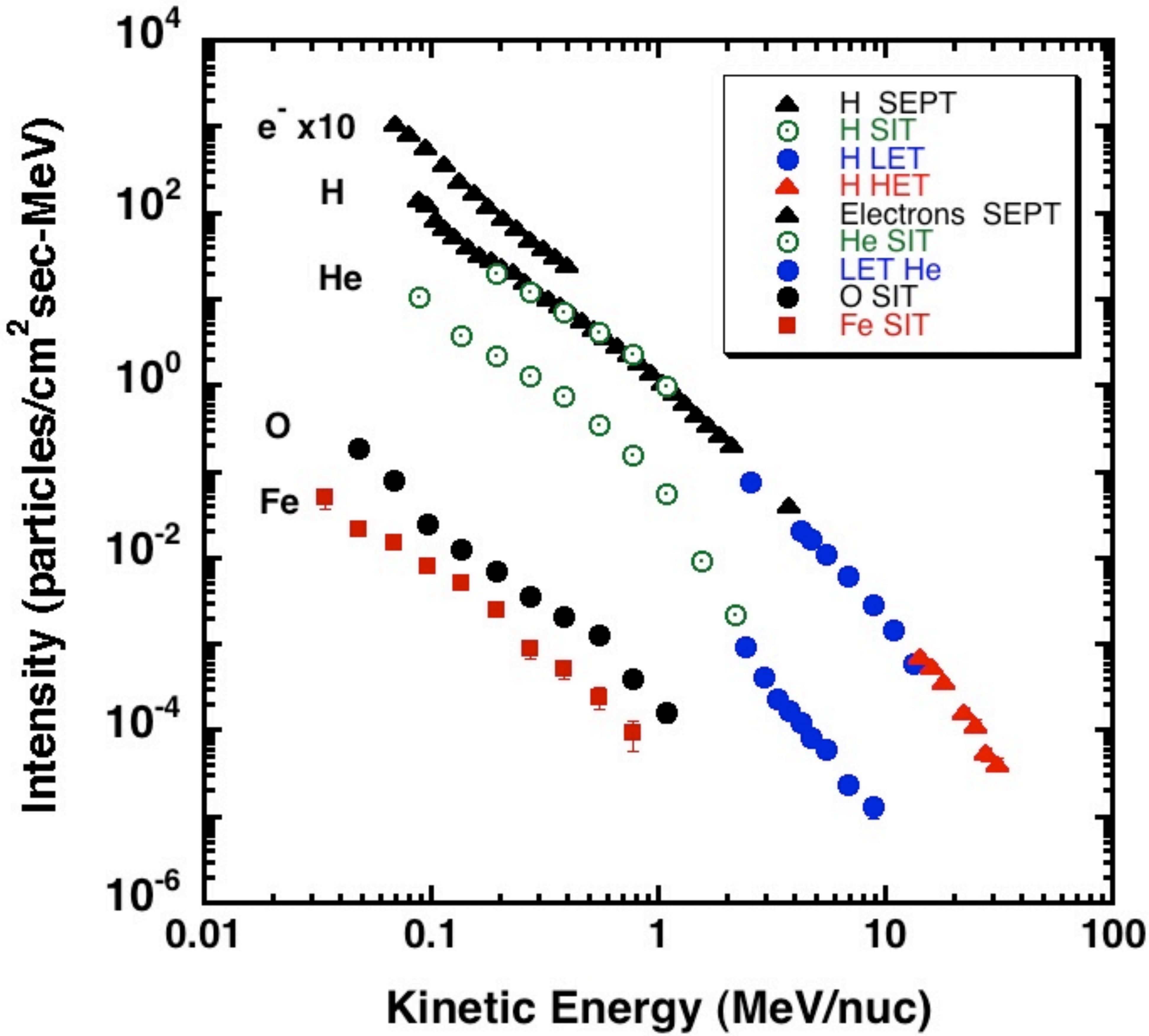
SEP Composition Measurements



- Abundances from the STEREO/LET sensor in the December 6 and 13, 2006 SEP events, relative to O and normalized to the coronal abundances of Feldman and Widing (2003)
- The two events differ dramatically in the abundances, particularly for elements heavier than Si
- The enhanced S-Fe in the December 13 event may be due to a contribution of flare-accelerated particles, whether directly or processed through the CME-driven shock
- The abundances of the December 6 event are fairly typical for large SEP events

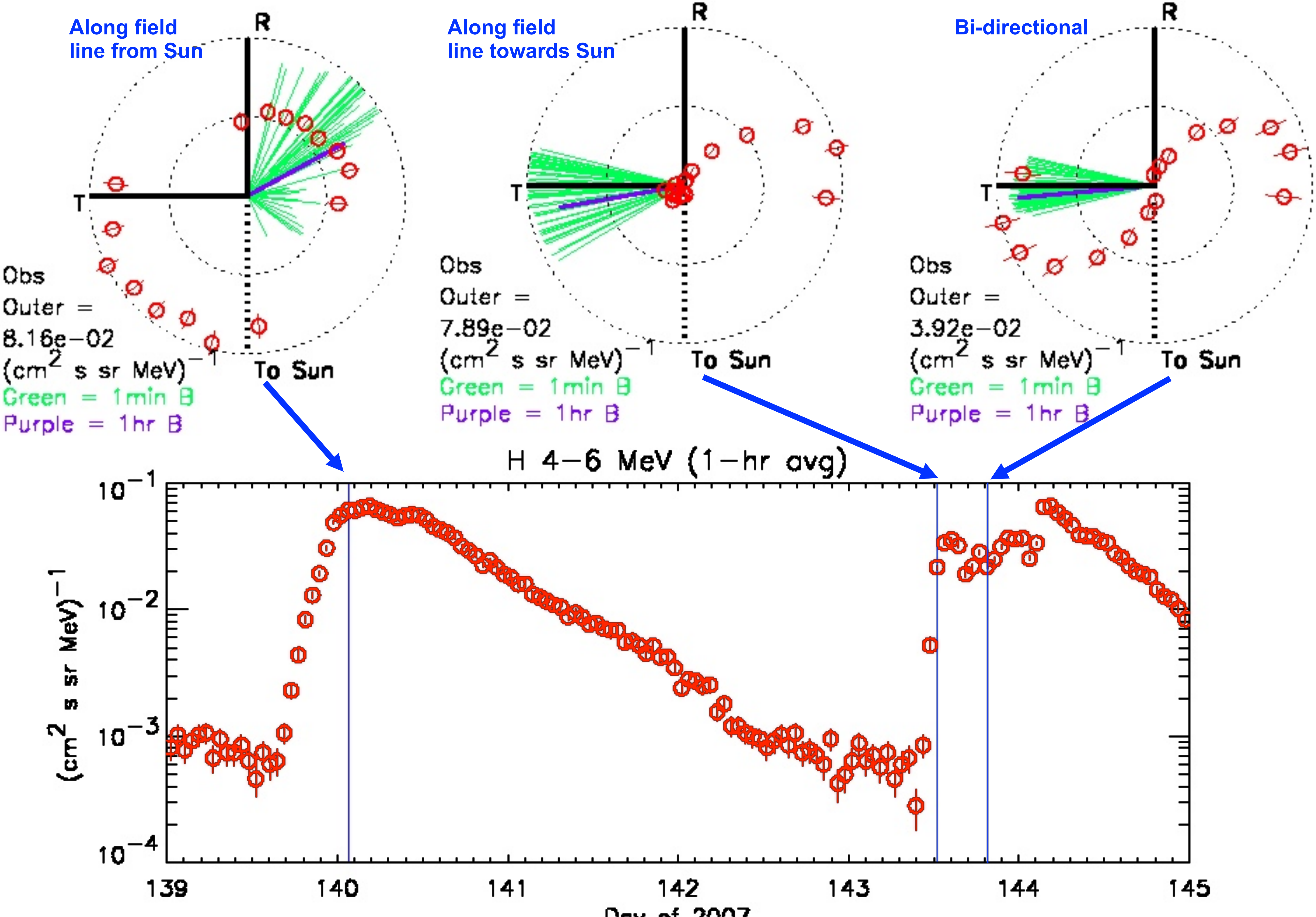
See Cohen et al. (2007, 2008), Mewaldt et al.(2007a, b); Malandraki et al. (2009)

STEREO/SEP Spectra from the small May 19, 2007 Event



The four SEP sensors make consistent measurements over a broad energy interval, even in small SEP events

Anisotropy measurements of 4-6 MeV H during May 2007 events



Observations Related to Objective 3F:

• Measured elemental abundances in December 2006 SEP events with typical uncertainties of a few percent (Cohen et al. 2007, 2008).

• Measured intensities of major species versus energy with typical uncertainties of ~3% (TBR) in the December 2006 events (Cohen et al. 2007, 2008; Mewaldt et al. 2007, Malandraki et al. 2009, von Rosenvinge et al. 2009)

• Measured time histories of major species with excellent statistical accuracy (Cohen et al. 2007, 2008, Mewaldt et al. 2007)

• Measured and fit SEP angular distributions over ~260° in longitude and correlated with magnetic field direction (Chollet et al., in preparation).

• Demonstrated good agreement with other spacecraft at 1 AU, including ACE, SAMPEX, and GOES (Mewaldt et al. 2007, Cohen et al. 2007, 2008).

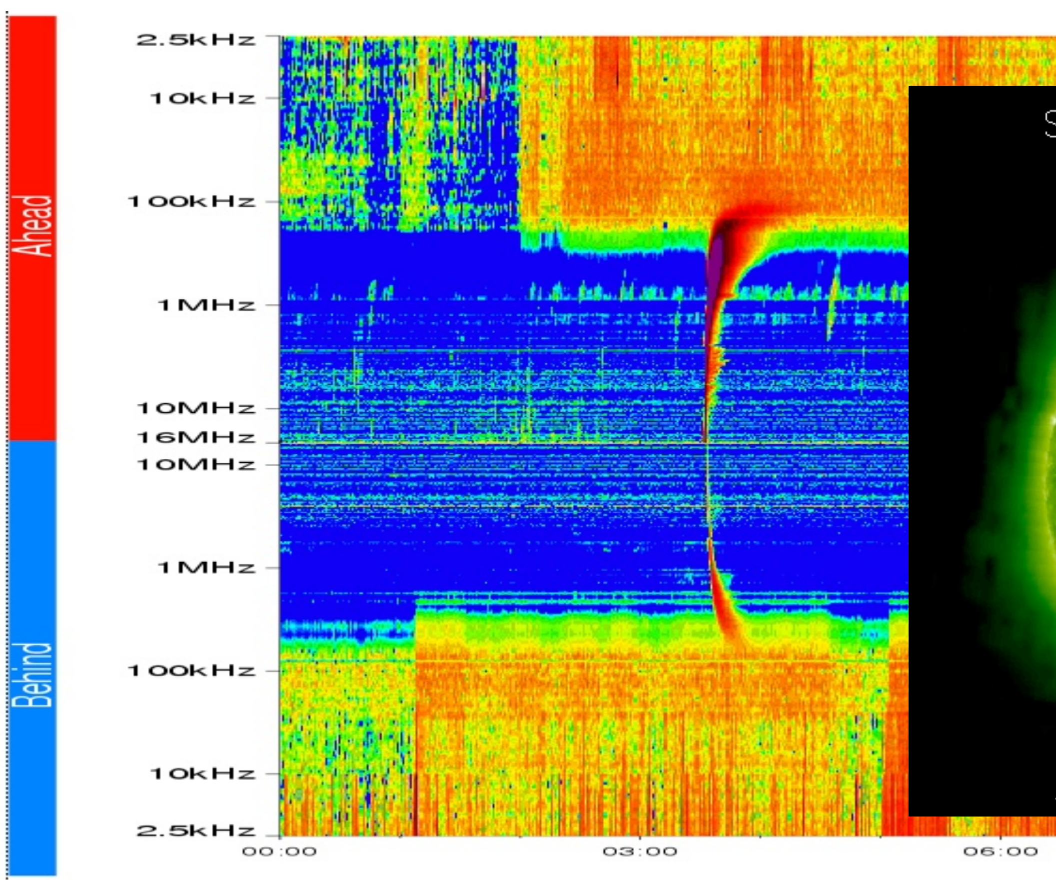
Electron velocity dispersion observed by SEPT during Nov. 3, 2009 SEP event

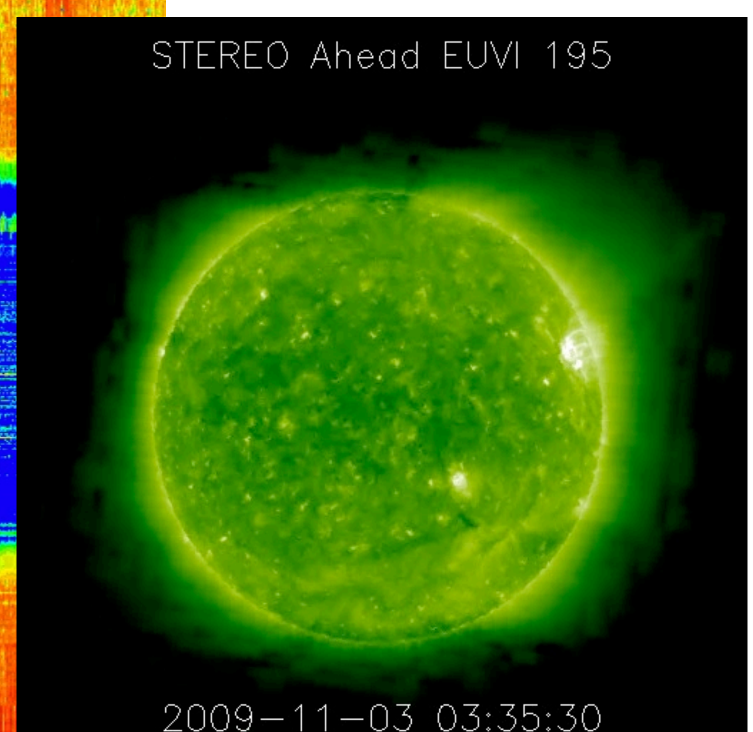
Source active region polarity corresponds to the new solar cycle 24

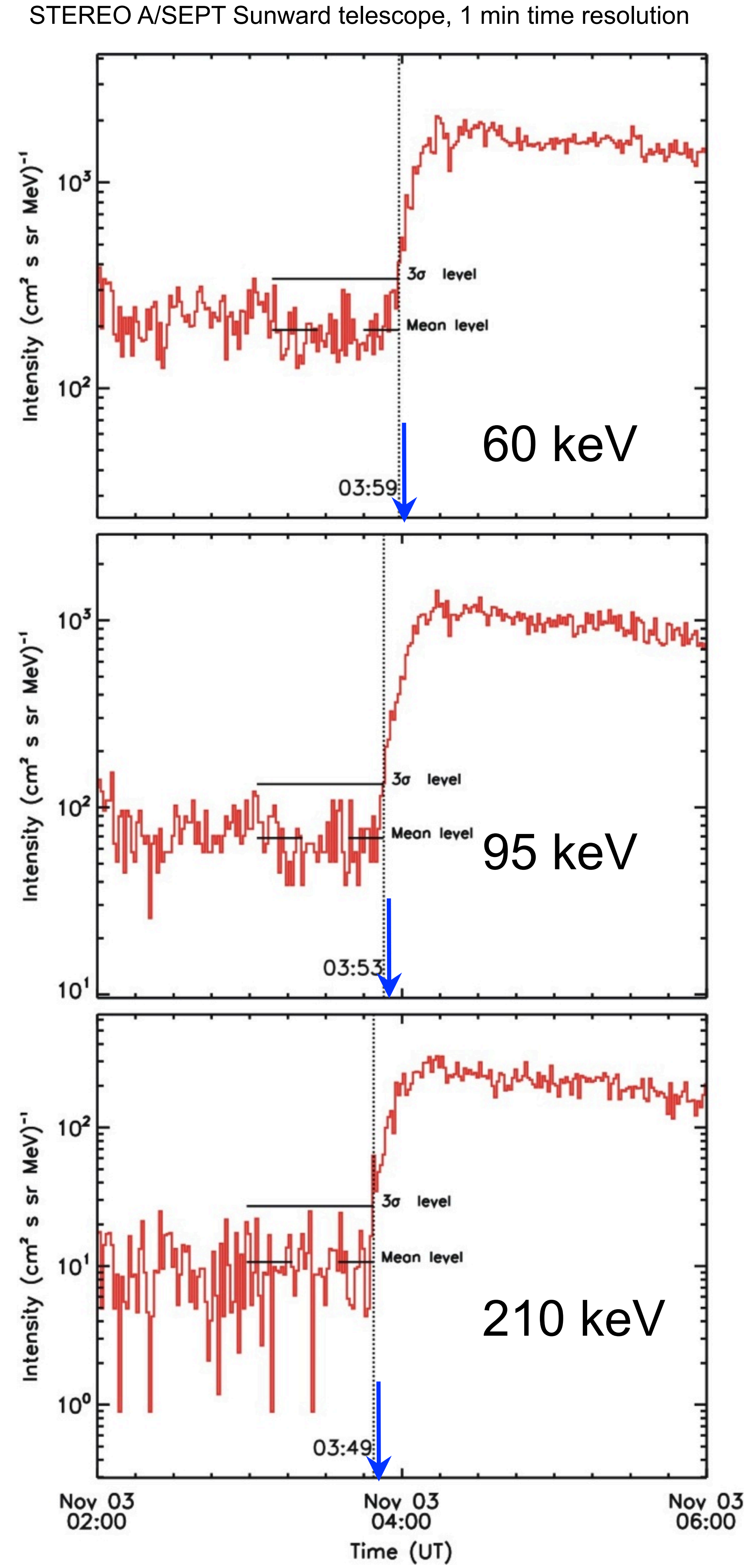
Event associated to a type III radio-burst observed by SWAVES

Type III onset time observed by Learmonth radio-station at 03:32 UT

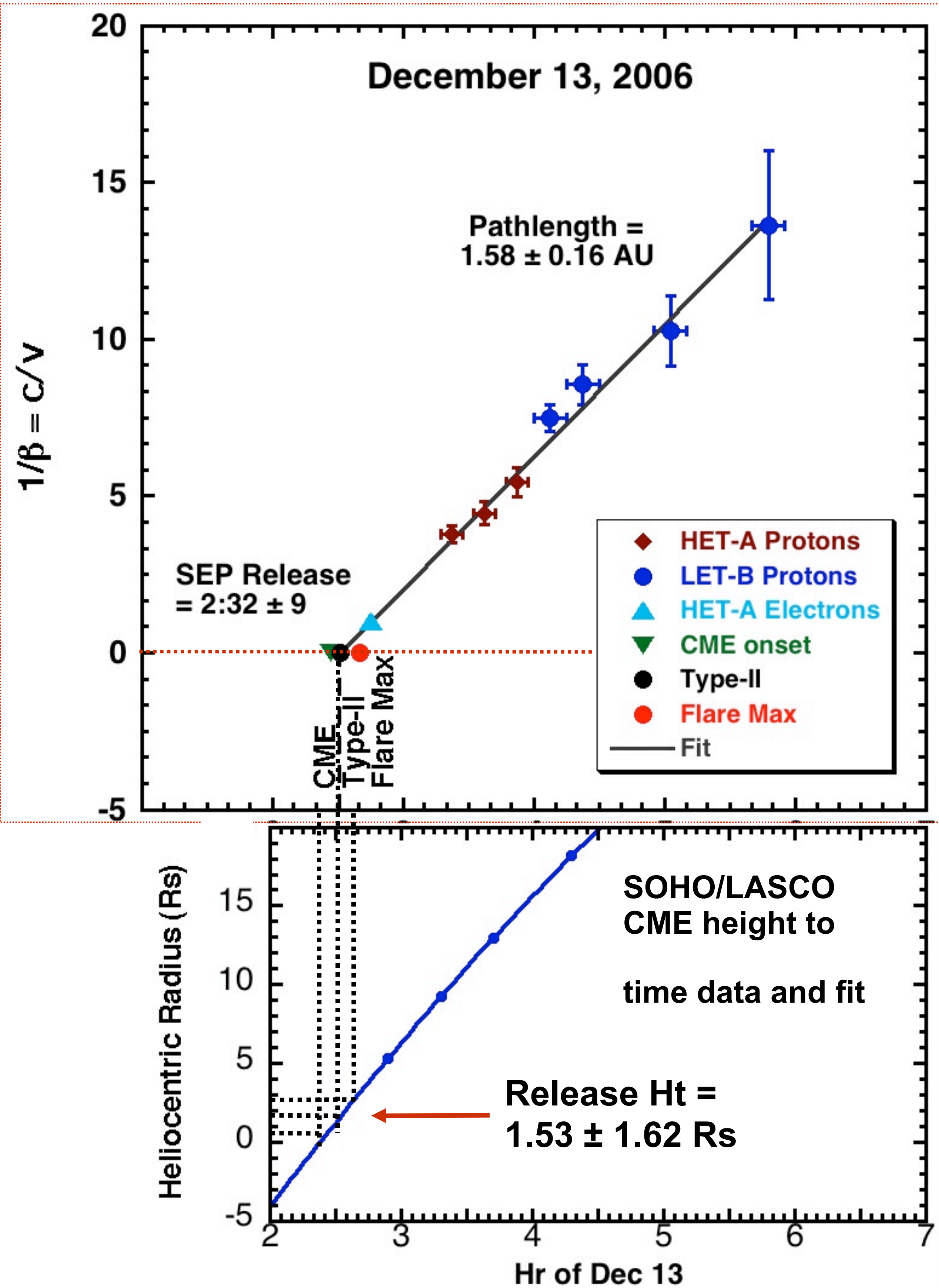
1 min resolution electron data shows clear velocity dispersion







When and where are SEPs released near the Sun?



A plot of onset times for protons with various energies versus 1/β reveals the SEP release time near the Sun.

The SEP release time in this event is consistent with either the x-ray flare onset or with shock acceleration by a CME driven shock, provided the shock forms low in the corona (within ~2 Rs of the solar surface)

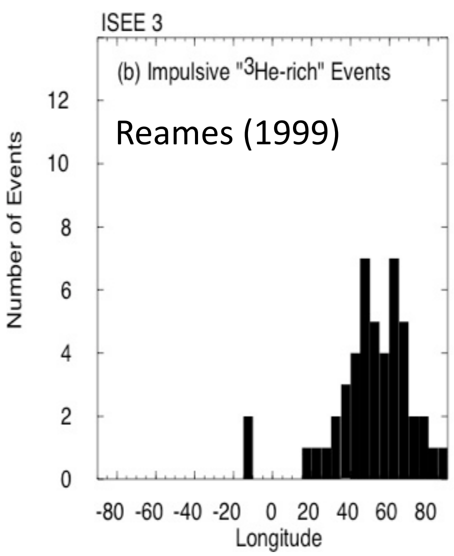
Electron velocity dispersion observed by SEPT during Nov. 3, 2009 SEP event

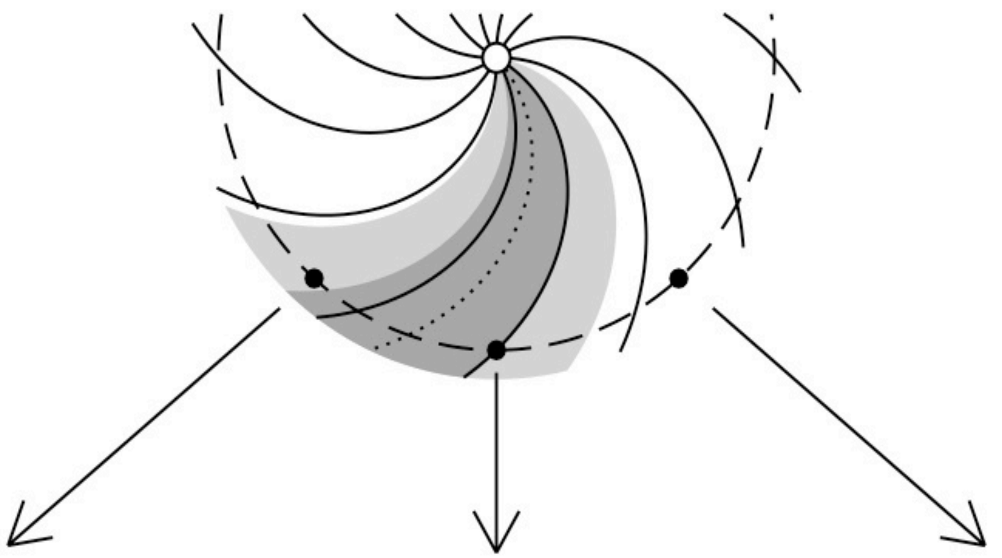
Similar delays were observed during solar cycle 23 (e.g. Krucker and Lin, 2000, Haggerty et al, 2002). These delays are not fully understood. Possible explanations include:

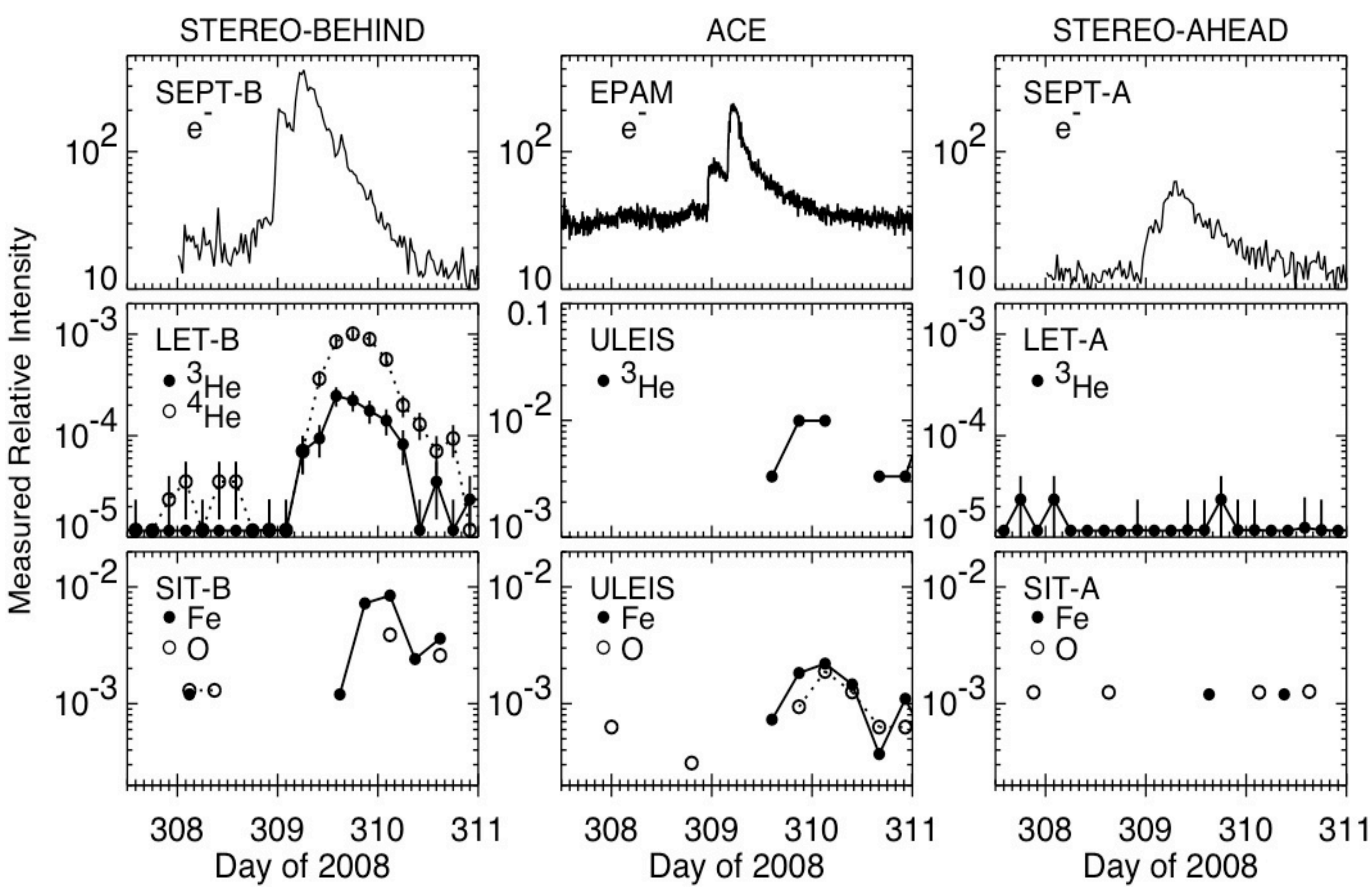
- Effects of interplanetary scattering (e.g. Saiz et al, 2005)
- Instrumental limitations for onset determination (background effects) (e.g. Laitinen et al., 2009)
- Delayed escape due to particle trapping
- Delayed injection, shock acceleration (e.g. Haggerty et al., 2002)

New multi-spacecraft in-situ and remote sensing observations and comparison with particle transport models are required to clarify the source of these delays.

Multipoint Observations of a ^{3}He-rich Solar Energetic Particle Event using LET, SIT, and SEPT on STEREO and ULEIS and EPAM on ACE







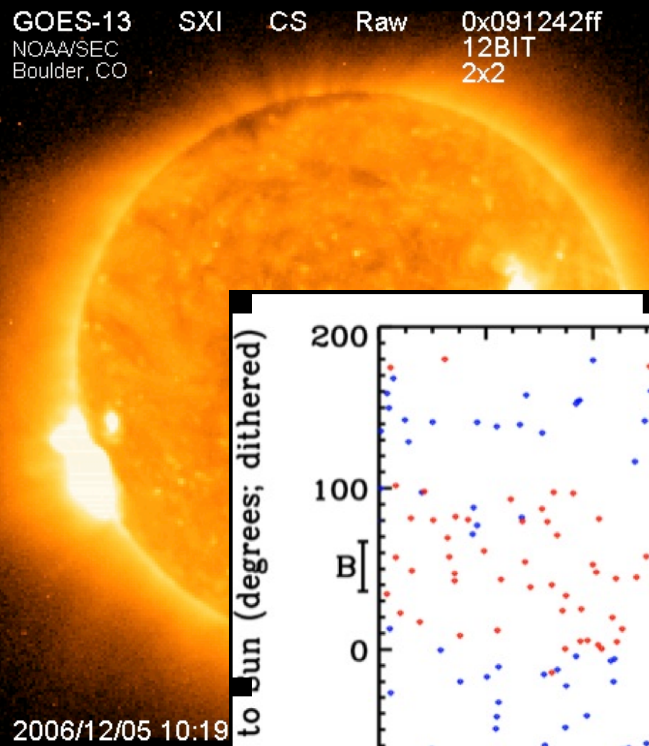
- A solar flare should act as an approximate point source of solar energetic particles (SEPs). The spread of SEPs seen at 1 AU should indicate how far open field lines from the active region have spread in heliolongitude. Previous single-spacecraft studies [inset] indicated ~20° rms spread at 1 AU about best connection to source region.

- In the event of 3-4 Nov 2008, the STEREO spacecraft were ~41° ahead and behind ACE.

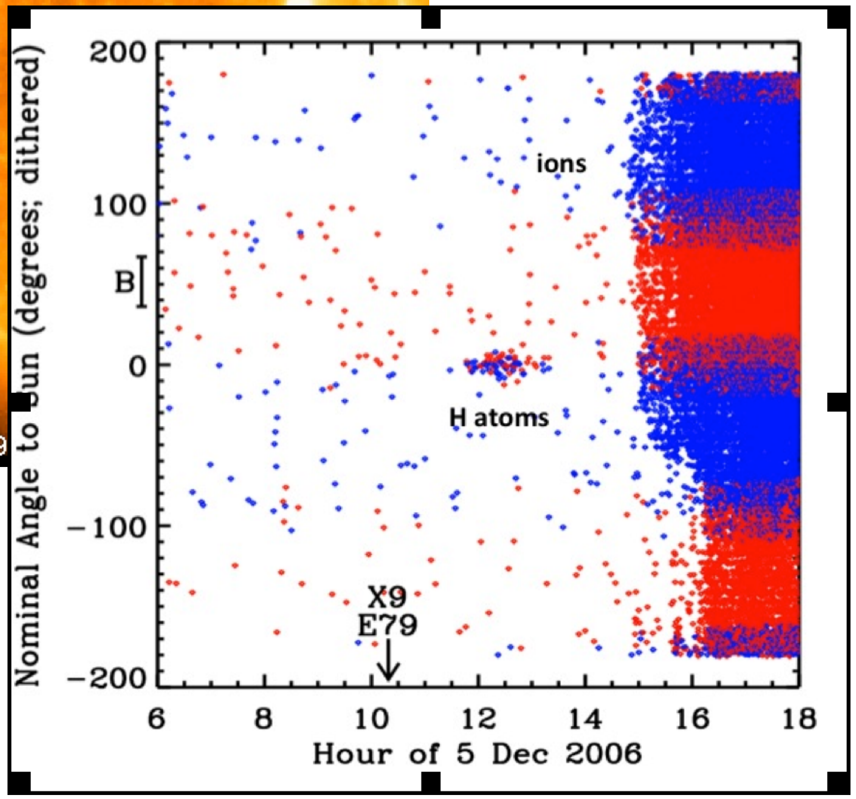
- Electrons were observed at all 3 spacecraft, ions at STEREO-B and ACE. Non-detection of ions at STEREO-A might have been due to sensitivity limitations.

- From the observations it is clear that the source region should be connected approximately mid-way between ACE and STEREO-B . This location is consistent with the one active region observed on the Sun (dotted spiral field line).

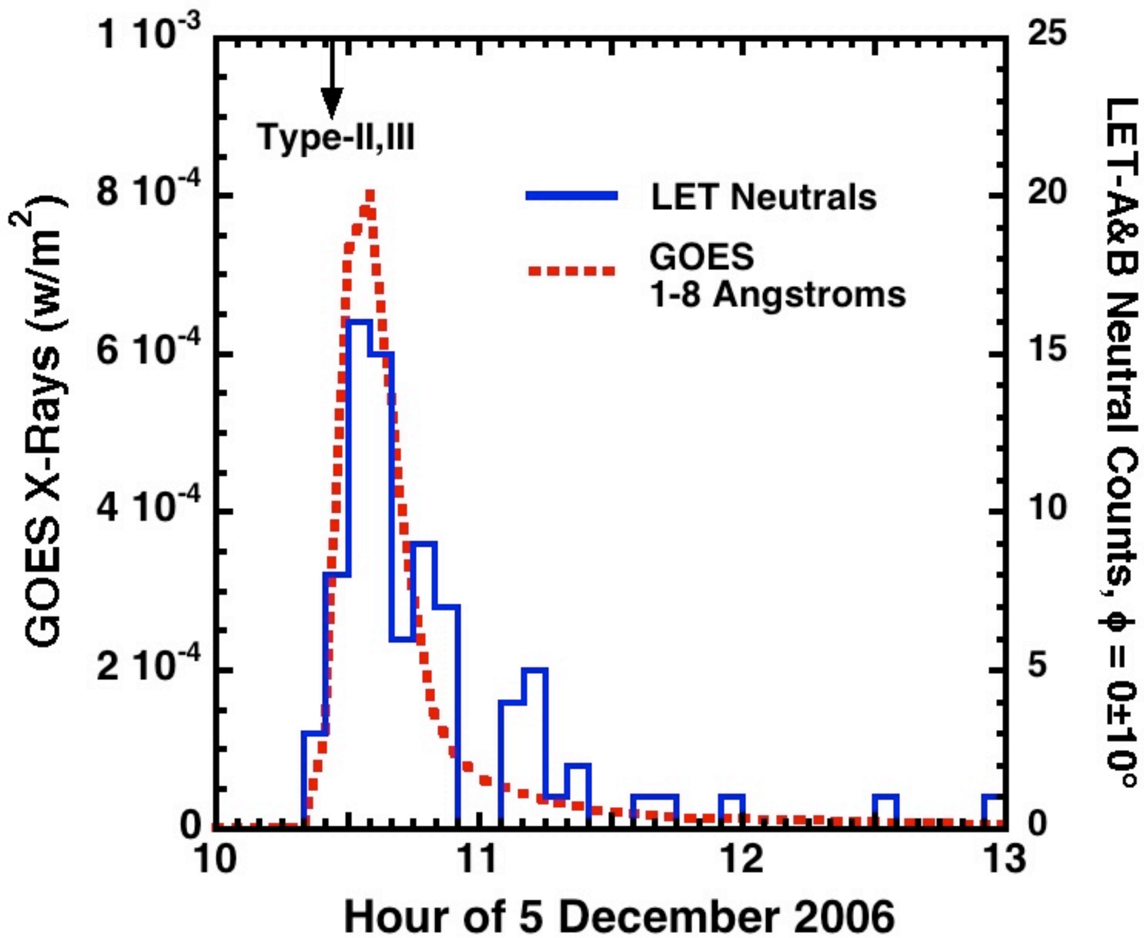
- Results to be published in Solar Wind 12 proceedings (Wiedenbeck et al. 2009).



On December 5, 2006, following an X9 solar flare, both LET sensors observed a burst of neutral H atoms from the Sun that preceded the main solar particle event by several hours

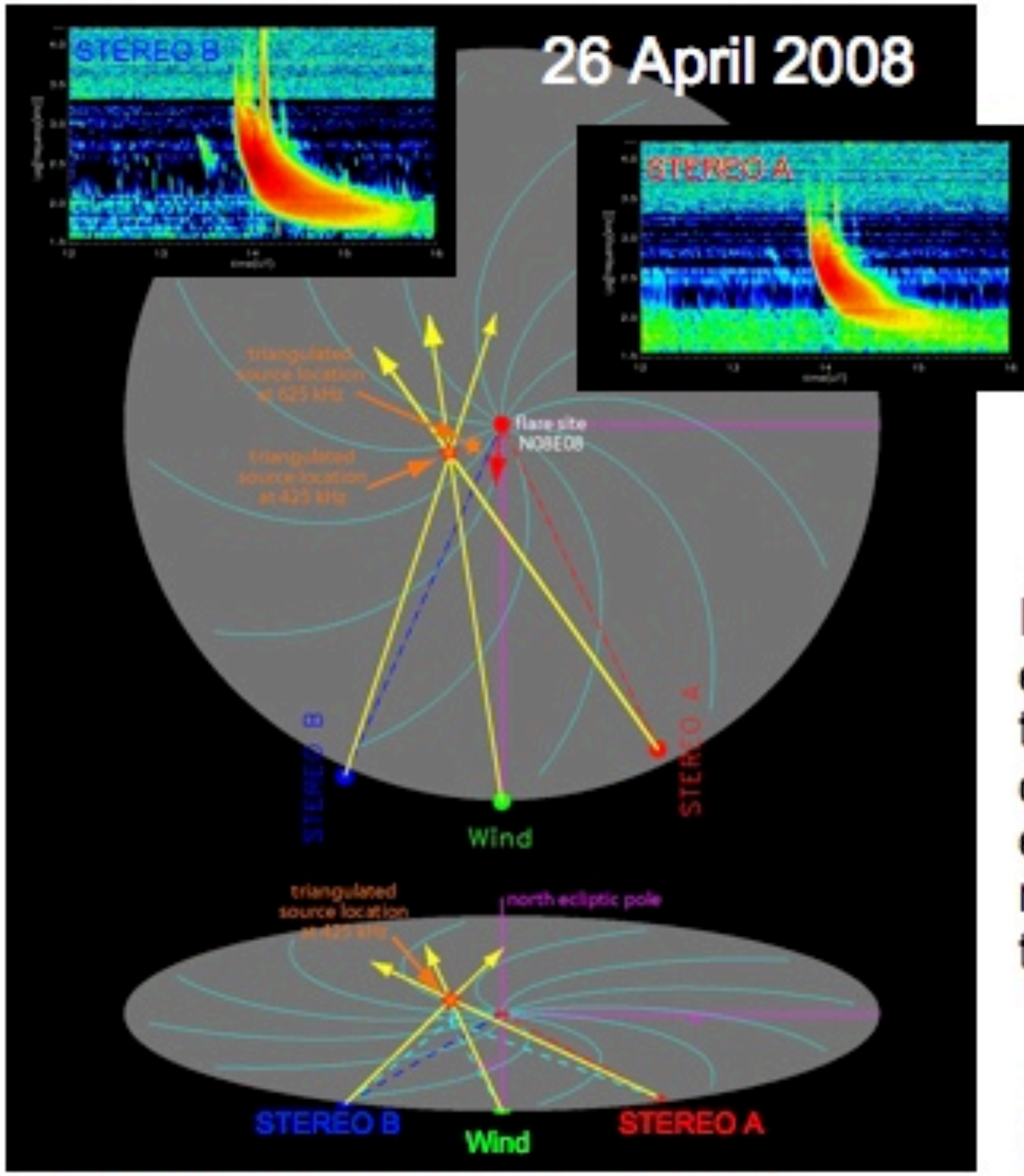


- The burst arrived from within ±10° of the Sun and was traveling across the magnetic field, => it must have been neutral
- Only neutral H atoms (ENAs) fit the observations. They must be produced when accelerated protons capture electrons
- The derived emission profile (based on the measured energy) agrees with the X-ray profile, but is also consistent with CME shock-accelerated protons



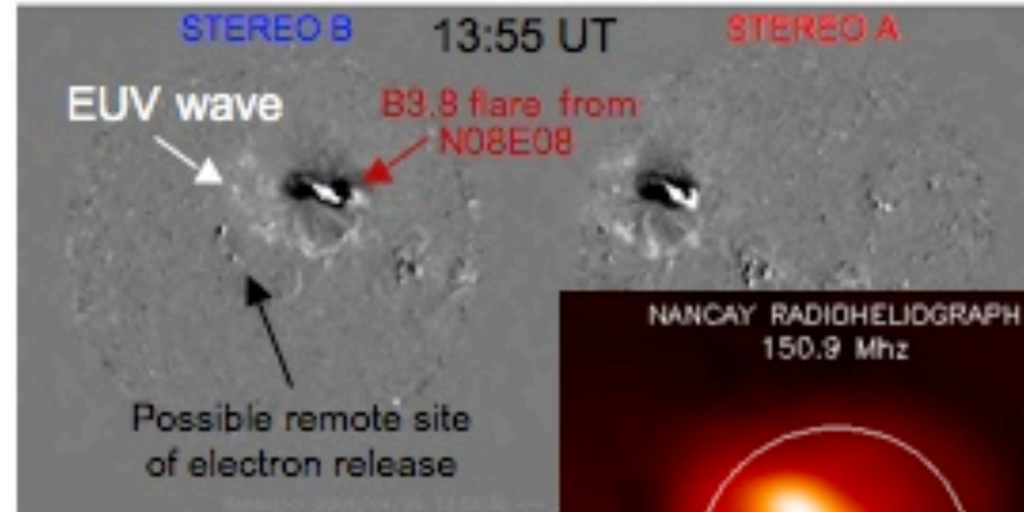
- Once produced, ENAs easily lose their electron. Therefore: They cannot escape from the reconnection site (<1.1 Rs) or flare footpoints, and must have been produced in the high corona (>2 Rs)
- ENAs reveal when and where accelerated protons interact with matter in the high corona

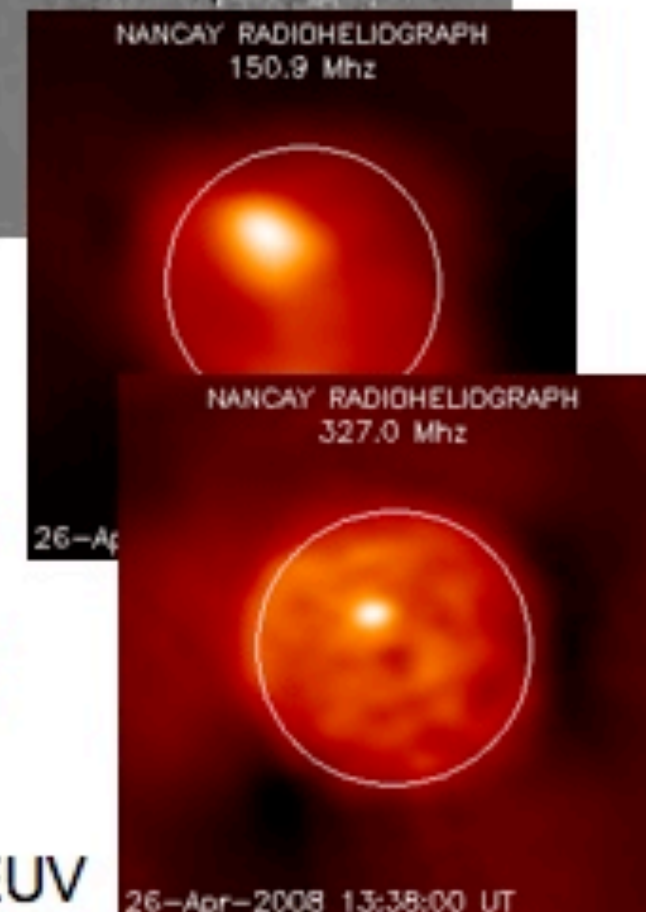
Relationship of the origin of type III bursts to solar features



For this type III burst, the triangulated radio source locations clearly indicate a solar origin of the electron beam along a Parker spiral from about E40°, while the flare occurred in the active region at about E08°. The radio source is also located well north of the ecliptic plane.

Work in progress - Possible interpretations



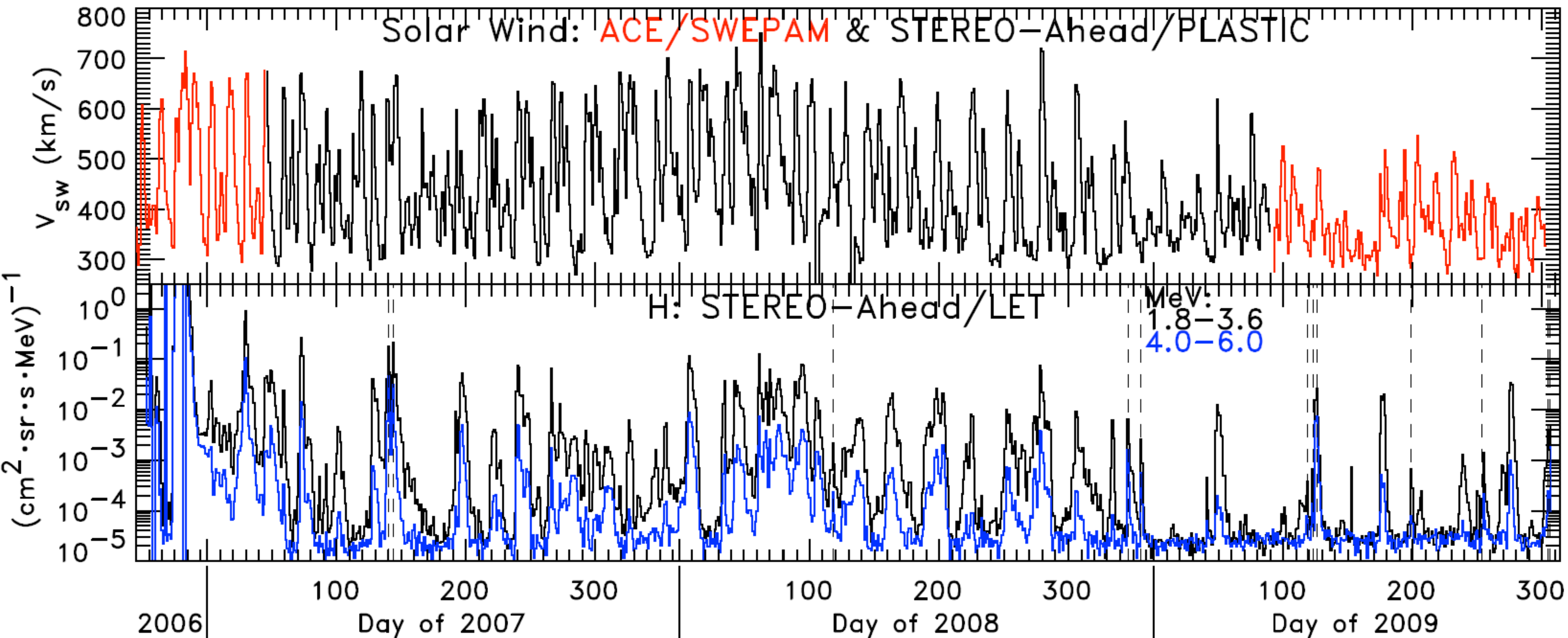


It is possible that the burst electrons were released at the flare site but were channeled along a flux tube extending eastward and northward, as suggested by the Nancy radioheliograph

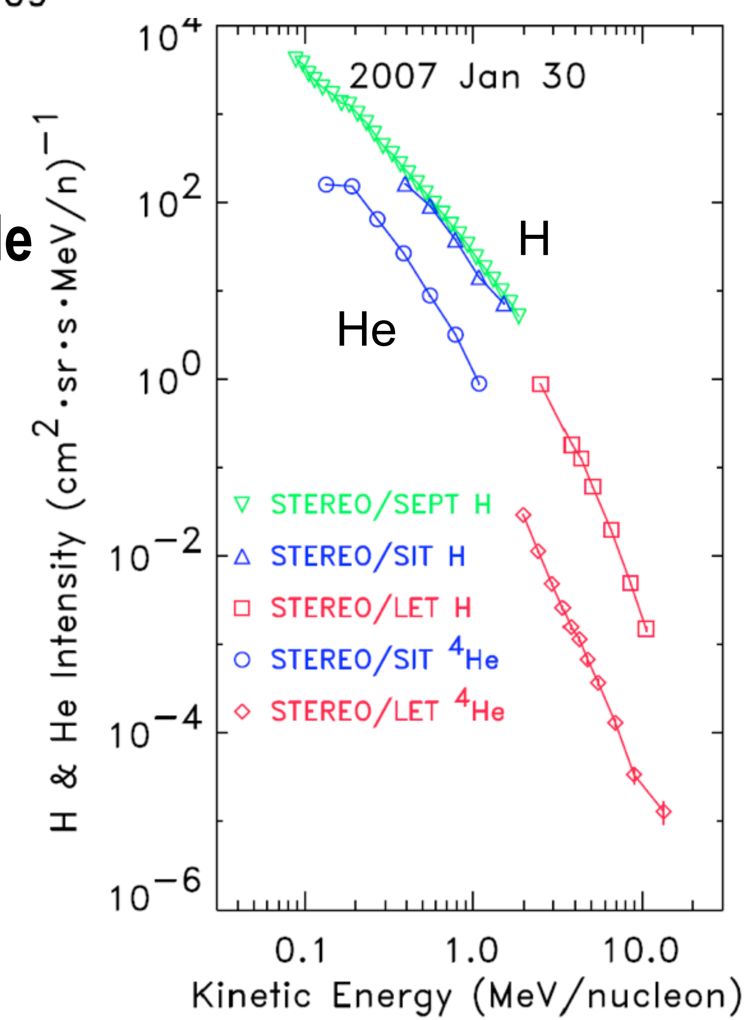
It is also possible that the EUV surface wave triggered the release of electrons at a remote site

Since we don't have a height-time plot for STEREO A, we can't yet estimate the height of the corresponding CME at the onset time of the type III burst

"Quiet-Time" CIRs from STEREO/IMPACT



CIR Energy Spectra from STEREO



- **Although the quiet Sun has produced very few, generally small SEP events (indicated by dashed lines above) during the STEREO prime mission, particle events associated with corotating interaction regions (CIRs) have been numerous, at least until 2009.**
- **The instruments of STEREO/IMPACT observe the spectra of CIR particles over >2 orders of magnitude in energy and ~8-9 orders of magnitude in intensity (right).**
- **CIR studies from STEREO include:**

  Mason et al., *Solar Physics* 256, 393 (2009)

  Gomez-Herrero et al., *JGR* 114, A05101 (2009)

  Leske et al., *AIP Conf Proc* 1039, 131 (2008)

Example of requirements satisfaction

Level 1 Reqquirements - SECCHI

Science Objectives	Sub Objectives	Level 1 Requirements	Instrument	Rel ID	Instrument Requirement		Satisfied By Paper
Understand the causes an mechanisms of CME initiation							
	CME Initiation Time						
		Determine the CME Initiation Time to an accuracy of order 10 minutes					Liewer, P.C., E.M. de Jong, J.R. Hall, R.A. Howard, W.T. Thompson, J.L. Culhane, L. Bone, and L. van Driel-Gesztelyi, Stereoscopic Analysis of the 19 May 2007 Erupting Filament, Solar Physics, 256, 57-72, 2009.; Patsourakos and Vourlidas 2009
			SECCHI EUVI	A	Take a series of sun-centered extreme ultraviolet images in low corona	√	
			SECCHI COR1	A	Take a series of sun-centered white light images from 1.3 to 3 Rsun	√	
	CME Initiation Location	Determine the location of CME initiation to within +/- 5 degrees of solar latitude and longitude					Thernisien, A., A. Vourlidas, and R.A. Howard, Forward Modeling of Coronal Mass Ejections Using STEREO/SECCHI Data, Solar Physics, 256, 111-130, 2009.; Patsourakos and Vourlidas 2009
			SECCHI EUVI	B	Take a series of sun-centered extreme ultraviolet images in low corona from two vantage points	√	
			SECCHI COR1	B	Take a series of sun-centered white light images from 1.3 to 3 Rsun from two vantage points	√	
			SECCHI COR2	B	Take a series of sun-centered white light images from 3 to 15 Rsun from two vantage points	√	
Characterize the propagation of CMEs through the heliosphere							
	CME Mass	Determine the evolution of the CME mass distribution and the longitudinal extent to an accuracy of +/- 5 degrees as it propagates in the low corona, the upper corona the interplanetary medium					Thernisien, A., A. Vourlidas, and R.A. Howard, Forward Modeling of Coronal Mass Ejections Using STEREO/SECCHI Data, Solar Physics, 256, 111-130, 2009. Colannino & Vourlidas(2009), Mierla et al (2009)